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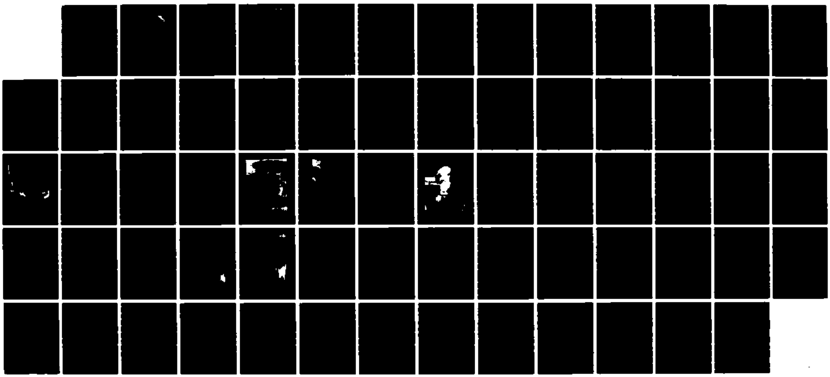

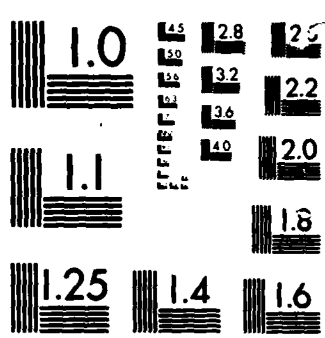

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FIREPROOF HYDRAULIC BRAKE SYSTEM

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Aircraft Systems Branch
Aircraft and Avionics Division
Directorate of Flight Test Engineering

April 1986

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4950TH TEST WING
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AFB, OHIO 45433-6513

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This report has been reviewed and is approved for publication.

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The Fireproof Hydraulic Brake System (FHBS) flight test program verified that the FHBS is a feasible method of eliminating aircraft hydraulic fluid fires ignited by hot brakes. The FHBS uses a new nonflammable hydraulic fluid, chlorotrifluoroethylene (CTFE), in the wheel well and landing gear area while retaining standard hydraulic fluid (MIL-H-5606) in the rest of the aircraft hydraulic system. The two fluids were separated downstream of the antiskid valve by a reservoir/separator unit. A C-135E was used as the test aircraft. The modification consisted of instrumentation to monitor brake system parameters and the FHBS installation for the left outboard wheel pair. The testing consisted of maximum effort braking runs at light aircraft gross weights to induce antiskid cycling. The FHBS was evaluated subjectively by the test pilot and objectively by comparing its performance with that of the standard C-135 brake system established by baseline testing.

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SUMMARY

1. The Fireproof Hydraulic Brake System (FHBS) was tested to determine the feasibility of a two-fluid brake system. The FHBS uses a new nonflammable fluid, chlorotrifluoroethylene (CTFE), in the wheel well and landing gear area while retaining standard hydraulic fluid (MIL-H-5606) in the rest of the aircraft hydraulic system. The new system was developed to eliminate the incidence of hydraulic fluid fires ignited by hot brakes.

2. The test aircraft was a C-135E with 5-rotor disc brakes and the Mark II Antiskid System. The FHBS consisted of modification of, or additions to, the hydraulic components downstream of the antiskid valve. Only the system for the left outboard wheel pair was modified. This was done as a safety precaution and because outboard tires skid more readily.

3. The testing was performed in two phases. First, baseline testing was conducted on the instrumented, but otherwise unmodified, aircraft. Then dedicated testing was performed after the installation of the FHBS. Each phase of testing consisted of numerous maximum effort stops at light weights to induce tire skidding and thus produce antiskid system cycling. A few stops were conducted on wet runways to observe more frequent cycling as a result of a reduced runway coefficient of friction.

4. Test data included wheel speeds, antiskid valve signals, hydraulic pressures measured at several locations, brake stack temperatures, brake torques measured by strain gauges located on landing gear components, and time correlated speed/position information obtained with a laser tracking unit. In addition, a detailed log was kept on all maintenance and service actions performed on the FHBS.

5. The results of the test indicated no discernable difference in performance of the FHBS as compared to the baseline brake system. The FHBS does not significantly increase brake system maintenance requirements. The new seals and components required for the FHBS withstood 59.9 flight hours of use including 34 maximum effort stops with antiskid cycling.

6. The FHBS is a feasible solution to the problem of brake hydraulic fluid fires. The system design could be tailored for each desired aircraft application. This design should consider system performance goals, system weight, and system reliability/maintainability.

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FOREWORD

1. This report covers the testing conducted between 28 May and 6 Nov 85 for the Fireproof Hydraulic Brake System, project no. 209804TP. All testing was performed at Wright-Patterson AFB, OH on aircraft C-135E/60-0375.

2. The author would like to acknowledge some outstanding contributions which made this program happen. Test pilots Maj Barton Henwood and Maj George London designed the aircraft operational procedures used in the test. Flight engineer SSgt Robert Meyer designed and fabricated adapters which connected air conditioner hoses with the aircraft wheels. This effort reduced the time needed for brake cooling using ground air conditioner carts by nearly half. Felix LeBlanc and Charles Hall planned, engineered, maintained, and assisted with the calibration of the extensive instrumentation package. MSgt Randy Holt coordinated the efforts of modification, maintenance, and instrumentation personnel to modify the aircraft for the baseline test phase. Richard Andy and John Franzen were invaluable in the reduction, organization, and analysis of the test data. Pneudraulics technician Terry Burkert was the hydraulics expert for the program. He assisted in revising service procedures, was consulted in correcting many design discrepancies in the FHBS modification kit, and assisted in the kit installation.

3. Special thanks go to the personnel of 4950th Test Wing Maintenance and of the 4950th Test Wing Aircraft Modification Center who installed the project modification on schedule despite having to correct many discrepancies with the FHBS modification kit.

4. The author would also like to recognize the efforts of Alan Whitney, the program manager from ASD/ENFEM, and Bruce Campbell, the representative from AFWAL/POOS. Their contributions to solving modification hardware problems helped to keep the program on schedule.

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INTRODUCTION

1. The occurrence of wheel well fires caused by flammable hydraulic fluid leaking onto ignition sources such as hot aircraft brakes is a continuing problem. To correct this, a new nonflammable hydraulic fluid and related system technology are being developed by the Air Force Wright Aeronautical Laboratories (AFWAL). The new fluid is a chlorotrifluoroethylene (CTFE) oligimer manufactured by the Halocarbon Products Corporation to which a 3M lubricity additive (0.05%) and a barium sulfonate rust inhibitor additive (0.5%) have been added by AFWAL/MLBT personnel. The CTFE fluid has met all of the nonflammability requirements established by ASD and AFWAL hazards personnel. The fluid is twice as dense as MIL-H-5606, yet it is slightly less viscous even at temperatures well below zero degrees Fahrenheit. It was determined in a previous AFWAL sponsored program that the use of the CTFE fluid thoughout an existing 3000 psi aircraft hydraulic system would impose a significant weight penalty.

2. The overall objective of this program was to demonstrate the feasibility of a two-fluid brake system which would utilize the nonflammable CTFE fluid exclusively in the high potential fire areas while the remaining portion of the system would use the lighter weight standard MIL-H-5606 fluid. AFWAL/POOS managed the laboratory development of the two-fluid brake system conducted by Boeing Military Airplane Company (BMAC) under Air Force contract no. F33615-83-C-2322. BMAC provided airworthy hardware and design data for the modifcation of the brake system on the left outboard wheel pair of a C-135 equipped with five-rotor brakes and the Mark II Antiskid System. The results of the BMAC laboratory development of the FHBS are documented in the final report AFWAL-TR-85-2072 (ref. 1). ASD/ENFEM was designated to provide overall program management of the flight test demonstration portion of the FHBS program. The 4950th Test Wing was designated as the responsible test organization.

3. The specific objectives of this program were:

a. Verify that the Fireproof Hydraulic Brake System achieved braking performance which is equivalent to the standard C-135 based upon a comparison of the following parameters:

(1) brake torque

(2) wheel speed

(3) brake pressure

(4) antiskid valve current

(5) brake temperature

b. Evaluate the maintainability and the supportability of a two-fluid brake system.

c. Evaluate the performance of the seals and components that have been

developed for use in the CTFE hydraulic fluid.

d. Evaluate the effect of the CTFE fluid on the static and dynamic performance of the brake system.

4. All project testing was performed at Wright-Patterson AFB, OH, on aircraft C-135E/60-0375. The testing included 74 maximum effort braking runs for data, 32 of which were performed after the FHBS kit was installed in July 1985. The other runs were conducted for baseline testing. Total dedicated project flight time was 10.3 hours. The FHBS remained on the aircraft for reliability/maintainablity testing for an additional 49.6 hours of flight time.

TEST ITEM AND INSTALLATION

1. The test item, the FHBS modification kit, was designed and fabricated by Boeing Military Airplane Company (BMAC). The test item was installed in aircraft C-135E/0375 (see Fig. 1), which has five rotor disc brakes and the Mark II Antiskid System. The Class II aircraft modification was performed at Wright-Patterson AFB by the 4950th Test Wing Aircraft Modification Center, Special Programs Division.

2. The standard C-135 brake system has one antiskid valve (one half of a dual unit) and one deboost valve for each of the four tandem wheel pairs. The FHBS consists of components which alter the standard configuration of the brake system downstream of the antiskid valve (see Fig. 2). The only newly designed hydraulic component is the reservoir/separator which is located just upstream of the deboost valve (see Fig. 2 and 3). The reservoir/separator keeps the two hydraulic fluids, MIL-H-5606 and CTFE, separated from each other by means of a piston. The reservoir/separator also provides a reserve supply of the CTFE fluid. Should a leak occur somewhere downstream of the reservoir/separator, the piston inside of the unit would bottom out and prevent the loss of fluid and system pressure upstream. Thus the hydraulic fuses used with the standard C-135 brake system are not needed with the FHBS and were removed. The deboost valve and reservoir/separator were mounted with the reservoir/separator on top in a framework attached to the side of the wheel well. The deboost valve was relocated to the aft part of the outboard wall of the wheel well (see Fig. 4). The hydraulic lines below the deboost valve were replaced by stainless steel lines of a larger diameter. In order to obtain dynamic response equivalent to the standard brake system, the line diameters were increased to compensate for the difference in fluid density and for the increased line length made necessary by the relocation of the deboost valve. All O-rings exposed to the CTFE fluid were made of modified phosphonitrilic flouroelastomer (PNF) manufactured by C. E. Conover and Company. The compound number was XF785. All hoses used with the CTFE fluid were lined with Teflon. In order to avoid the accidental mixing of fluids, the FHBS service fittings were made a different size from the service fittings of the standard system. The CTFE fluid service cart, manufactured by Tronair, is shown in Figure 5.

3. Only the left outboard wheel pair was modified on the test aircraft. Early in the program it was decided that the modification of all of the brakes with an unknown system was an unnecessary risk. The overall test objective only required testing the feasibility of the FHBS.

4. After the installation was completed, the FHBS as serviced with CTFE up to the 80% level of the reservoir/separator, the normal operating level. The system was pressure checked for leaks. A landing gear retraction check was performed to check for adequate clearances.

INSTRUMENTATION AND TEST EQUIPMENT

1. The data acquisition system consisted of signal conditioning amplifiers and a pulse code modulation (PCM) recorder mounted in a double-bay shock mounted rack with the tape recorder mounted separately on a shock mounted table (see Fig. 6 for photo and Fig. 1 for location). Wheel speeds and brake temperatures were monitored on board the aircraft using real time digital displays. The aircraft instrumentation data was recorded at 50 samples per second in PCM format onto magnetic tapes.

2. A variety of transducers were used, as follows:

a. Hydraulic pressure transducers were used to sense pressures going into and out of each antiskid valve, and to sense pressures at all eight brakes (see Fig. 7).

b. The antiskid control shield test connection was tapped to record all antiskid valve signals and wheel speeds.

c. Sixteen thermocouples were used to measure brake stack temperatures. One thermocouple was welded onto each of the number two and number three brake stators for all eight main gear wheels. The thermocouple attachment point is shown in Fig. 8.

d. Strain gauges were mounted onto landing gear components as shown in Fig. 9 in order to derive brake torques.

e. The aircraft's fuel totalizer was used to calculate the aircraft's gross weight to within 1000 pounds.

3. Other test equipment used included an automated laser tracker for time, speed, and position information (see Fig. 1 for retroreflector locations). The system used at Wright-Patterson AFB is the Precision Approach Area Tracking System (PAATS). The PAATS data was recorded on magnetic tapes at 100 samples per second. This unit also recorded videotape of the testing for a visual history. Time code generators were employed to correlate the aircraft and PAATS data tapes by setting both units to the National Bureau of Standards WWV time standard.

4. General observations and weather conditions were hand recorded.

5. Ground air conditioner carts were used to cool the brakes to near ambient temperatures prior to the subsequent test run. Special adapters were fabricated to connect the air conditioner hoses to the wheels, thus reducing turn-around time by ensuring maximum airflow over the brake assemblies.

TEST PROCEDURES

1. The testing was conducted in two phases: baseline and FHBS. The baseline testing was conducted after the installation of only the test instrumentation. The purpose of the baseline test phase was to establish the performance of the unmodified C-135 brake system. After the completion of the baseline testing, the FHBS modification kit was installed. Then the FHBS test phase was conducted to determine the performance of the new system. Additionally, the aircraft flew on routine training missions for 49.6 hours with the FHBS "piggybacked." Piggybacking is defined as flying the test item on board the aircraft with no instrumentation in use. The purpose of the piggyback testing was to gain additional reliability and maintainability data.

2. A two part parking brake test was performed prior to taxi testing after the FHBS was installed. The parking brakes were set for two hours and brake pressures were compared at the beginning and the end of that time period. The FHBS was inspected for any fluid leaks. In addition, parking brakes were then checked with the engines developing takeoff rated thrust (TRT).

3. Preflight procedures called for the inspection of all visible brake system components from the wheel wells down to the brakes for fluid leaks and for line and component mounting integrity. The reservoir/separator was inspected to ensure an adequate CTFE fluid level. Tire and oleo strut pressures were checked prior to each braking run to ensure consistency.

4. Taxi testing was performed prior to the baseline and FHBS test phases to functionally check the aircraft brake systems and test instrumentation, while producing sample data.

a. The aircraft was taxied at normal ramp speeds with periodic braking to a complete stop. Then repeated rapid brake applications were performed while noting aircraft and brake responses. Differential braking was checked. The copilot's brakes were also checked for proper operation. For the FHBS test phase, the aircraft was towed clear of other aircraft before the taxi tests were initiated.

b. After these slow speed taxi tests, two high speed runs with maximum effort braking were conducted. The aircraft gross weight was 150,000 lbs. The configuration was standard for takeoff (flaps set at 20 degrees). The aircraft was accelerated as per a static takeoff. With the engines at idle and the speed brakes deployed, the brakes were applied at 50 knots ground speed for the first run. The inertial navigation sytem (INS) was used to display ground speed. For the second run, the brakes were applied at 70 knots ground speed with the aircraft in the same configuration. At 25 knots on both runs, the brakes were released and then immediately reapplied at less than maximum effort to prevent wheel locks below 18 knots, the minimum speed for antiskid system operation. Reverse thrust was to be used only for an emergency situation.

5. The baseline and FHBS test procedures were identical. The test points with the number of brake runs desired for each phase are listed in Table 1. All testing was conducted at relatively light aircraft gross weights in order to promote tire skidding and thus induce antiskid cycling. All test runs were

conducted within plus or minus 5000 lb of the desired gross weight. Procedures for the rejected takeoff runs were the same as the high speed taxi runs, with the exception of different brake application speeds and aircraft gross weights. From the experience gained in the high speed taxi tests, the engine throttles were reduced to idle seven knots prior to reaching the brake application speed plus the headwind component. This ensured sufficient time for engine spool down prior to braking and minimized overshoot of the brake application speed.

6. The landing runs were conducted in a similar manner, except that the aircraft was flown and then landed in the normal landing configuration (flaps at 50 degrees). After deploying the speed brakes, the brakes were applied upon reaching the designated brake application speed. The wet runway test points were conducted to check for abnormal performance at a lower runway condition reading (RCR) where more frequent antiskid cycling is seen. Only a small number of these runs were planned due to the difficulty of getting ideal weather conditions.

7. The go/no go criteria for each test run were as follows:

a. Winds at or below 10 knots (including gusts) and crosswinds at or below 5 knots were required.

b. Minimum weather conditions for the landing tests were 500 ft. ceiling and two miles visibility.

c. All test instrumentation including PAATS had to be operational, with the exception that only one good thermocouple per wheel was required.

d. Brake temperatures were required to be below 150 degrees Fahrenheit prior to the subsequent braking run.

e. Tires were required to have identical pressures within normal maintenance specifications and a comparable amount of tread wear.

f. Main gear shock strut pressures were required to be identical and within normal maintenance specifications.

g. The level of CTFE fluid in the reservoir/separator was required to be at the 80% level at the start of a mission day. The maximum fluid leakage acceptable during a mission day was 5%.

DATA REDUCTION AND ANALYSIS

1. Data Reduction

a. All aircraft instrumentation data was stripped out with a Brush recorder after half of a day of testing for quick-look. Instrumentation problems could then be noted and corrected prior to further testing. The strip charts were also used to monitor brake system performance.

b. The aircraft instrumentation data was then transferred to computer compatible tape for further processing. This included converting the data to engineering units, printing the data in tabular listings, and correlating the data with the PAATS tracking data.

c. Total energy absorbed by each brake for each test run was computed using two different methods:

(1) Brake temperatures were translated directly into brake energies by using laboratory test data from Bendix report EAL-64-75 (Ref. 2). In the laboratory test, Bendix applied known torques to the KC-135 5-rotor brake assembly and measured the resulting peak stator temperatures with thermocouples. This data is linear for the range of brake energies achieved during the FHBS test project as shown in Fig. 11. As observed in the baseline test phase, the brake stators reached their temperature peaks at different times. Often one of the two thermocouples used on each brake was inoperative. Time history plots of brake stator temperatures from FHBS test data were used to determine when to sample the data for a reliable indication of peak brake temperatures. The time selected was 60 seconds after the aircraft came to a stop. An example of such a plot is shown in Fig 12. The stack temperature of brake rotors and stators always reached thermal equilibrium within 60 seconds. Even when temperature peaks were reached in only 15 seconds, the amount of cooling seen by 60 seconds was insignificant. The brake temperatures sampled at 60 seconds after the stop were converted into brake energies by using the equation of the best fit line through the Bendix data points.

(2) Brake energies were also computed by integrating the measured braking forces over the brake application distance. Each rear wheel braking force was derived from the brake reactive torques measured by strain gauges placed on each equalizer rod (see Fig. 9). The total front wheel braking force was obtained by subtracting the sum of the rear wheel forces from the total braking force derived from the forces measured on the landing gear drag link. Since the brake pressures for each tandem wheel pair is controlled by the same antiskid valve, the ratio of energy between front inboard and outboard wheels was assumed equivalent to the ratio of brake energies for the rear inboard and outboard wheels. Thus, the individual brake energies for the front wheels could be estimated.

d. Tables were made of all of the brake energies derived by the two methods described (Tables 2 through 17). A table was generated for each test condition for each test phase. The energies are listed in the same layout as the wheels of the main landing gear (see Fig 13). Additionally, a predicted energy value was calculated for each run on a dry runway using the brake

performance chart on page 5-35 of T.O. 1C-135(K)E-1 (ref. 3). This value represents an average brake energy per wheel. Actual test conditions were used as the chart input values. According to BMAC, the curves on this chart are slightly conservative as a safety margin.

e. Scatter plots of the brake energies were made (Fig. 14 through 17) which compare the average energy of the left outboard wheel pair to that of the right outboard wheel pair. These plots were made for both the strain gauge and the thermocouple derived brake energies for each test phase. The plots show for each test condition the differences in average brake energies achieved at the outboard wheels for each stop. The diagonal line on each scatter plot represents the line at which the values for the x and y axes are equivalent. Additionally, a scatter plot for each method of brake energy derivation was generated comparing the baseline to FHBS left outboard average brake energies at each test condition (Fig. 18 and 19).

2. Analysis of Brake Energy Data

a. The primary criterion for assessing the FHBS performance is whether or not equivalent brake energy absorption is achieved during antiskid cycling when compared to the standard system. For light aircraft gross weights, the canting of the landing gear is such that the normal force pressing down on the inboard wheels is greater than that on the outboard wheels. As a result, the outboard tires skid more readily, yielding more frequent antiskid cycling. The outboard brakes absorb less energy since the outboard brake stacks do not remain compressed as long with the increased cycling. For many runs the inboard brakes experienced no antiskid cycling and remained compressed for the entire stop. For this reason, only the outboard wheel brake energies were used to compare the FHBS performance with the standard system.

b. Some limitations were inherent in the conduct of the test. Even after controlling as many test variables as possible, brake testing data may differ by as much as 15% on identical runs according to Air Force Flight Test Center experts. Another constraint was that only a few runs were performed at each test condition. Although reducing the number of test conditions would have increased the number of data samples for the remaining test conditions, this would have precluded testing the FHBS for performance consistency under a variety of conditions.

c. The following method was used to quantify any performance difference between the FHBS and the standard C-135 brake system. The energy absorbed by each outboard brake of the FHBS was compared with the energy absorbed by each outboard brake of the standard system for each test condition. The brake energies for the standard system included data from both the left and right outboard wheels from the baseline test phase as well as the brake energies from the right outboard wheels of the FHBS test phase. The difference in absorbed brake energy was computed for each pairing of an FHBS brake energy with a standard system brake energy by subtracting the energy of the standard system brake from that of the FHBS brake. An average difference in brake energy for each test point was computed using all possible paired observations available for each test condition. This was done for both methods of computing brake energies (see Table 18). A composite average difference was calculated by weighting the average difference available at each test point according to the number of paired observations. This difference would be an

indication of the difference in brake system performance over all of the test conditions.

3. Brake System Frequency Analysis

a. Transfer functions were generated for comparing frequency responses of the FHBS with the standard brake system. (See Fig. 20 and 21 for samples.) A dual-channel fast Fourier transform (FFT) analyzer was used to accomplish this. The system "input" signal was a voltage proportional to the antiskid valve output fluid pressure. The system "output" signal was a voltage proportional to the fluid pressure at the brake. Since the data was recorded at 50 samples per second, the available bandwidth for analysis was limited to less than 25 Hertz (Hz). The coherence function was also generated from this data to measure the linear dependence of the output signal to the input signal. A high percentage of coherence indicates that the system input/output relationship is well described by the computed transfer function.

4. Analysis of Test Item Components and Fluid Samples

Hydraulic fluid samples were analyzed by personnel of the AFWAL Materials Laboratory. The fluid samples were checked for any indications of CTFE fluid and MIL-H-5606 fluid mixing caused by malfunctioning reservoir/separator seals. CTFE fluid samples were also analyzed for other sources of contamination and for degradation. The FHBS components were analyzed by the AFWAL/POOS and ASD/ENFEM personnel. The components were disassembled and inspected for wear or degradation.

TEST RESULTS AND DISCUSSION

1. Baseline Test Phase

a. The baseline test phase achieved the goals of characterizing the standard C-135 brake system performance, troubleshooting the test instrumentation, and refining the procedures used for test conduct and support.

b. A characteristic of the C-135 maximum effort stopping performance at light gross weights is that the inboard brakes absorb more energy than the outboard brakes. The brake energies for each test run are listed in Tables 2 through 9. The canting of the landing gear at light gross weight reduces the normal force pressing down the outboard wheels as compared to that on the inboard wheels. This allows the outboard tires to skid more readily. The strip charts revealed more frequent antiskid cycling for the outboard wheels and little or no cycling for the inboard wheels. Thus the inboard brake stacks remained compressed longer and absorbed more energy. As a result, only the brake energies for the outboard wheels could be used to compare brake system performance.

c. During the testing for test point one, a problem with the antiskid system for the left outboard wheel pair was discovered. A corroded electrical multi-pin connector was inducing noise in the signal from the wheel speed transducer to the antiskid control shield. The control shield was sensing this noise as skidding and thus was cycling the antiskid valve even before brakes were applied. Once brakes were applied, the excessive antiskid cycling reduced the effective brake pressure to a third of what would be normal. The pilot was able to see the aircraft pull strongly to the right as a result. Detecting the source of the noise in the wheel speed signal proved to be difficult and several test runs were rendered useless for baseline data. Normal antiskid system checks failed to find the problem.

d. Test point three was deleted after three runs since little or no antiskid cycling was seen. Without the lift of fifty degrees of flaps at this heavier gross weight, the normal force on the tires was too great. In addition, stops at this test condition caused considerable brake wear.

e. Brake energies derived from test data are similar for both methods of derivation. These energies also track well with the predictions calculated by using the brake energy chart from the aircraft operating manual. However, the derived brake energies at test point 6 (180,000 lb gross weight) were approximately two million ft-lbs less than the C-135 brake energy chart prediction (see Table 7). The conservatism built into the chart is a possible explanation for this.

f. The weather conditions necessary to perform the wet runway testing did not occur during the time available for this test phase. This was not considered critical since the wet runway test conditions were desired only to check for abnormal performance at a lower runway condition reading (RCR). Data from the unmodified right outboard wheels collected during the FHBS test phase was used as a baseline.

2. FHBS Test Phase

a. The parking brakes remained set for the two hour test period with no loss of pressure. No leaks were detected. In addition, the parking brakes held with the engines advanced to TRT.

b. Normal brake responses were observed for both the slow and high speed taxi runs.

c. The pilot could not detect any difference in directional control as compared to the baseline testing.

d. The brake energies calculated for each run for each test condition are listed in Tables 10 through 17. Scatter plots of the average left outboard versus average right outboard brake energies are shown in Fig. 14 through 17. Scatter plots of the standard system versus FHBS average left outboard brake energies are shown in Fig. 18 and 19. Each point represents the average brake energy for each test condition. The results of the statistical analysis of brake energies are listed in Table 18. The composite average difference in brake energy absorbed for all test conditions was small. This average difference, weighted by the number of paired brake energy observations (refer to data analysis section), represents the average difference in brake energies absorbed by the FHBS as compared to the standard system. The larger average difference of the two methods of computing brake energies was 0.59 million ft-lb greater for the standard system as compared to the FHBS. This represents a difference in performance of seven percent.

e. The analysis of the brake system frequency response showed a maximum difference in gain of five decibels (dB) when comparing the standard system dynamic response to the FHBS (see Fig. 20 and 21). The frequency analysis data is considered valid up to approximately five Hz. Brake pressure signal noise (as evident in Fig. 22) prevented analysis above five Hz. Boeing tested the system frequency response in the laboratory up to 50 Hz. The results can be found in AFWAL-TR-85-2072 (ref. 1).

f. On a test run at 180,000 lbs. gross weight, a tee fitting mounted atop the brake (see Fig. 7) for the number five wheel cracked allowing most of the CTFE fluid to spray onto the tires and brakes. The peak brake temperatures reached on this run were approximately 1100 degrees Fahrenheit. The CTFE fluid that came into contact with the hot brake surfaces vaporized but did not burn. If the MIL-H-5606 fluid had leaked, a fire could have resulted since the flash point of MIL-H-5606 fluid is only 220 degrees. Also, the reservoir/separator prevented the loss of the MIL-H-5606 fluid pressure as designed. The standard C-135 brake system uses hydraulic fuses to retain system pressure in the event of such a leak. Although unplanned, this incident was a demonstration of the fire protection capability of the FHBS.

3. Logistics Evaluation

The FHBS was simple in design and simple to service. The reservoir/separator - deboost valve assembly was easily accessible for inspection or servicing. The FHBS is designed to require only a one step bleed process. The fittings on the FHBS and the CTFE fluid service cart were different in size from fittings on the standard hydraulic system in order to

prevent an accidental mixing of fluids. AFWAL's preliminary test results indicated that the CTFE fluid is safe for handling by personnel. No incidents occured which were contrary to those results.

4. Fluid Sample Analysis

Analysis of fluid samples taken during the FHBS test phase showed no sign of fluid mixing due to seal leakage in the reservoir/separator unit. The CTFE fluid showed no sign of decomposition or contamination.

5. FHBS Component Inspection

No corrosion was found on any of the metal components. No scoring was found on any of the sliding metal components. The MIL-H-5606 fluid spring energized seal in the reservoir/separator unit had to be replaced once during the test program due to fluid leakage. The PNF O-ring seals showed only slight traces of wear in the deboost valve and no sign of wear in the reservoir/separator unit or in the brake assemblies.

CONCLUSIONS AND RECOMMENDATIONS

The Fireproof Hydraulic Brake System (FHBS) program is a feasible concept for eliminating aircraft brake hydraulic fluid fires. The specific conclusions are listed relative to the specific test objectives.

1. No significant difference in performance could be detected from analyzing strip charts of the brake system technical parameters. In addition, the pilot could not detect any difference in directional control from maximum effort stops conducted before and after the FHBS was installed. A comparison of energies absorbed by the outboard brakes over all test conditions indicated that the FHBS brakes absorbed approximately three to seven percent less energy.

2. The FHBS does not significantly impact maintainability.

a. The FHBS is simple in design. The FHBS is easily serviced and maintained as long as accessibility is ensured.

b. Chlorotrifluoroethylene (CTFE) fluid appears to be safe for personnel to handle and requires no special handling precautions.

3. The seals and components designed for use with the CTFE fluid showed no sign of decomposition and little or no sign of wear after the repeated cycling of 34 maximum effort braking runs and 59.9 flight hours of operation.

4. The FHBS modification did not significantly affect the static or dynamic performance of the C-135 brake system.

a. The parking brakes showed no performance degradation with the FHBS installed.

b. A comparison of brake system dynamic response revealed a difference in gain of less than five dB up to five Hz, the maximum frequency of observable data. Since brake energy absorbtion by the two systems were comparable, this difference is not considered significant.

RECOMMENDATION - THE FIREPROOF HYDRAULIC BRAKE SYSTEM DESIGN SHOULD BE TAILORED FOR EACH AIRCRAFT MODEL TO ACHIEVE PERFORMANCE GOALS, MINIMIZE WEIGHT, AND ENSURE MAINTAINABILITY.

REFERENCES

1. Huling, D. W. and Hillman, H. F., Fireproof Hydraulic Brake System, AFWAL-TR-85-2072, Air Force Wright Aeronautical Laboratories, Wright-Patterson AFB, Ohio, October 1985.

2. Vetter, Charles H., Dynamic Torque, Rejected Takeoff Stop and Structural Torque Test of a Bendix 17 1/4" X 11 1/2" - 5 Rotor Brake Assembly, Part No. 2600380(2600380-1), KC-135, EAL-64-75, Bendix Aircraft Brake and Strut Division, Allied Corporation, South Bend, Indiana, January 6, 1965.

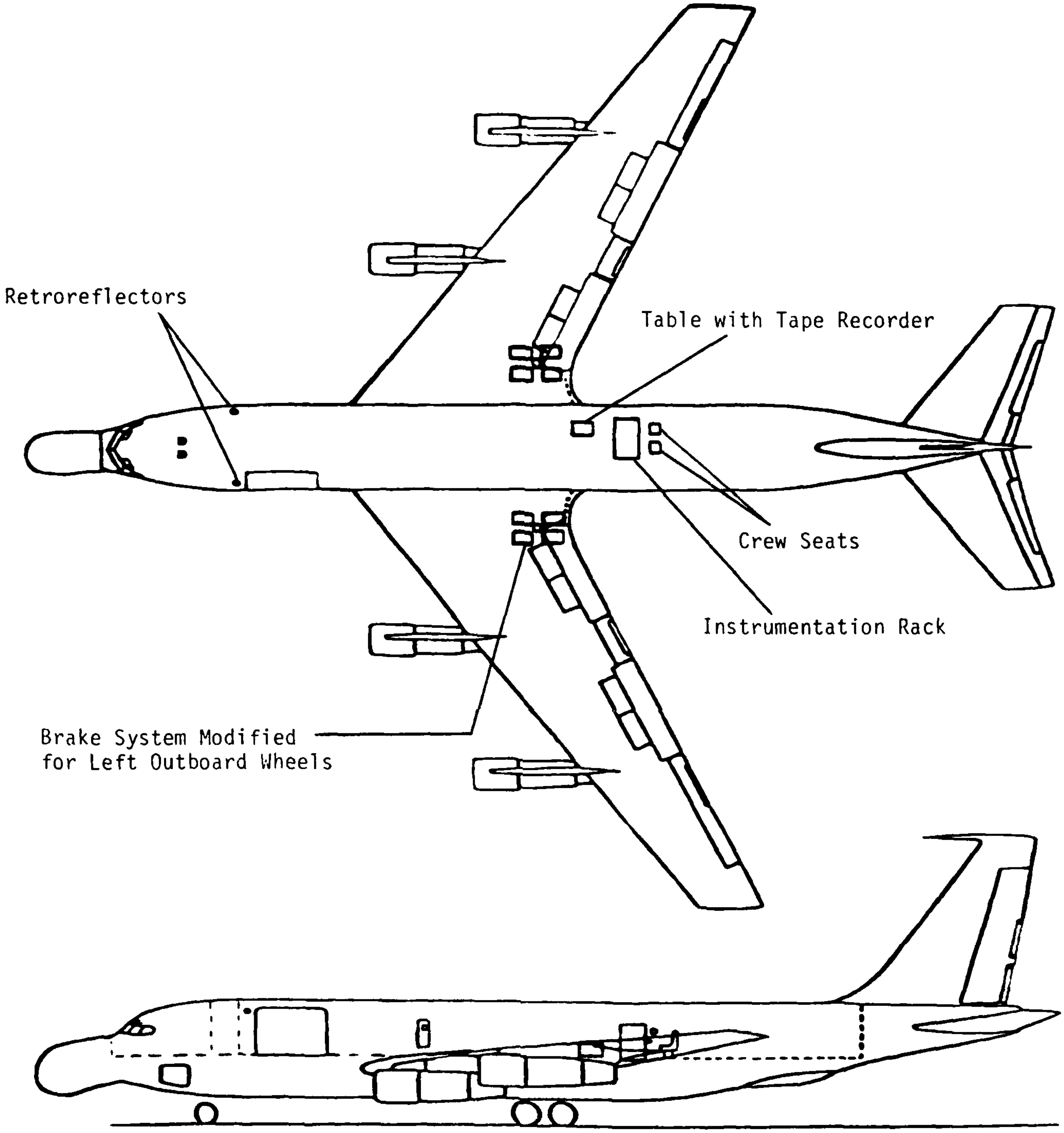
3. USAF Series C-135E and KC-135E Aircraft Flight Manual, T.O. 1C-135(K)E-1, October 15, 1982.

LIST OF ABBREVIATIONS

Item	Definition
AFWAL	Air Force Wright Aeronautical Laboratories
ASD	Aeronautical Systems Division
BMAC	Boeing Military Airplane Company
CTFE	Chlorotrifluoroethylene
dB	Decibel
FFT	Fast Fourier Transform
FHBS	Fireproof Hydraulic Brake System
Hz	Hertz
INS	Inertial Navigation System
PAATS	Precision Approach Area Tracking System
PCM	Pulse Code Modulation
PNF	Phosphonitrilic Fluoroelastomer
RCR	Runway Condition Reading
RTOs	Rejected Takeoffs
TD	Test Director
TRT	Takeoff Rated Thrust

APPENDIX A

ILLUSTRATIONS



C-135E/60-0375

FIGURE 1 - TEST AIRCRAFT

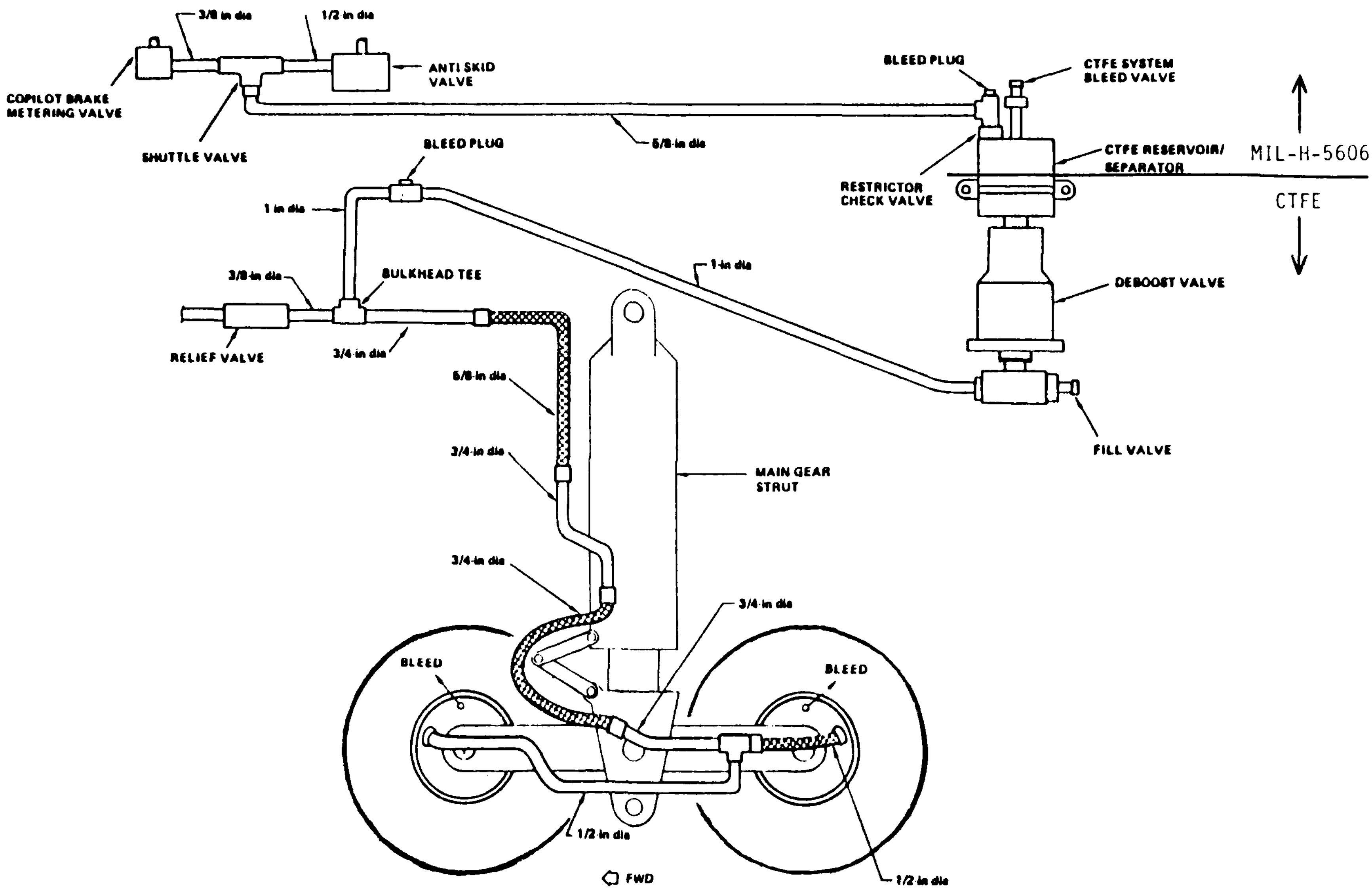
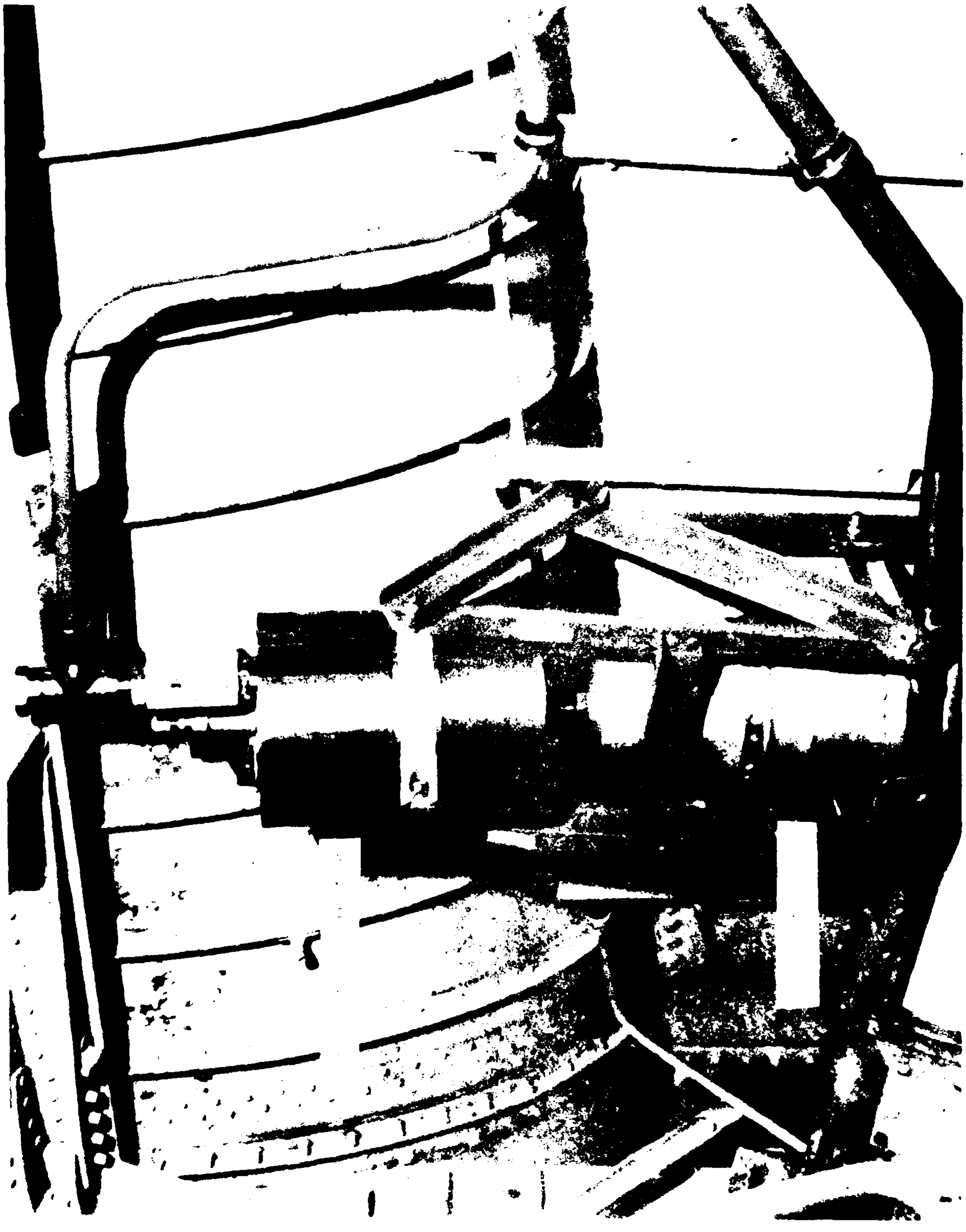
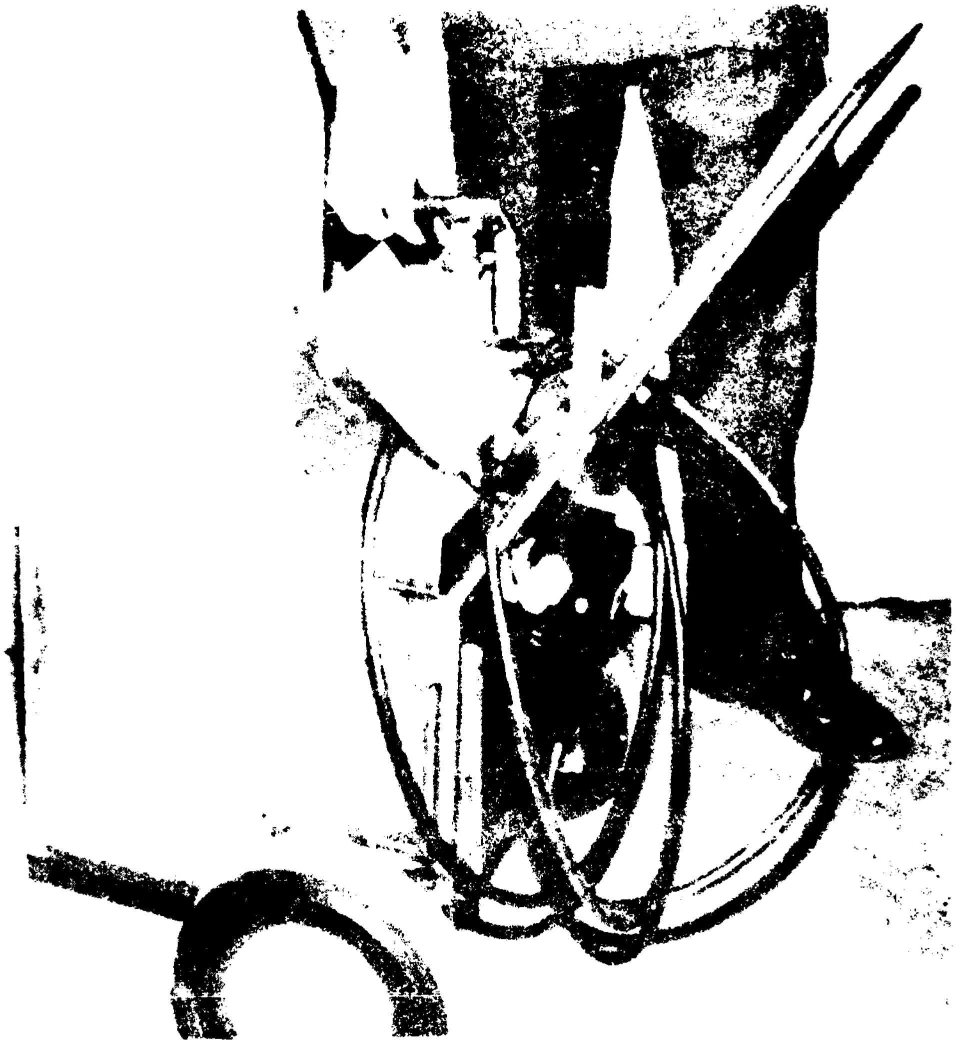
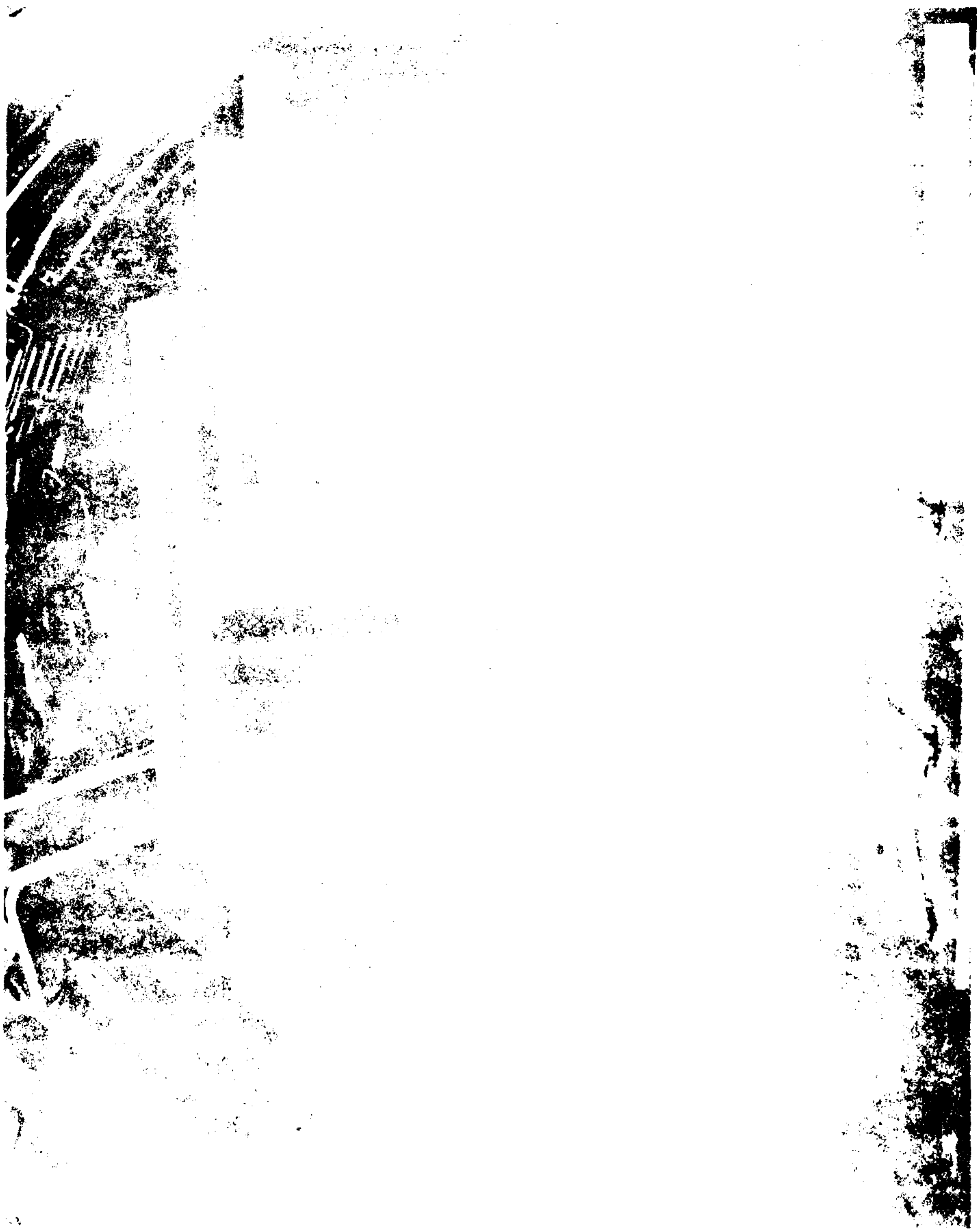
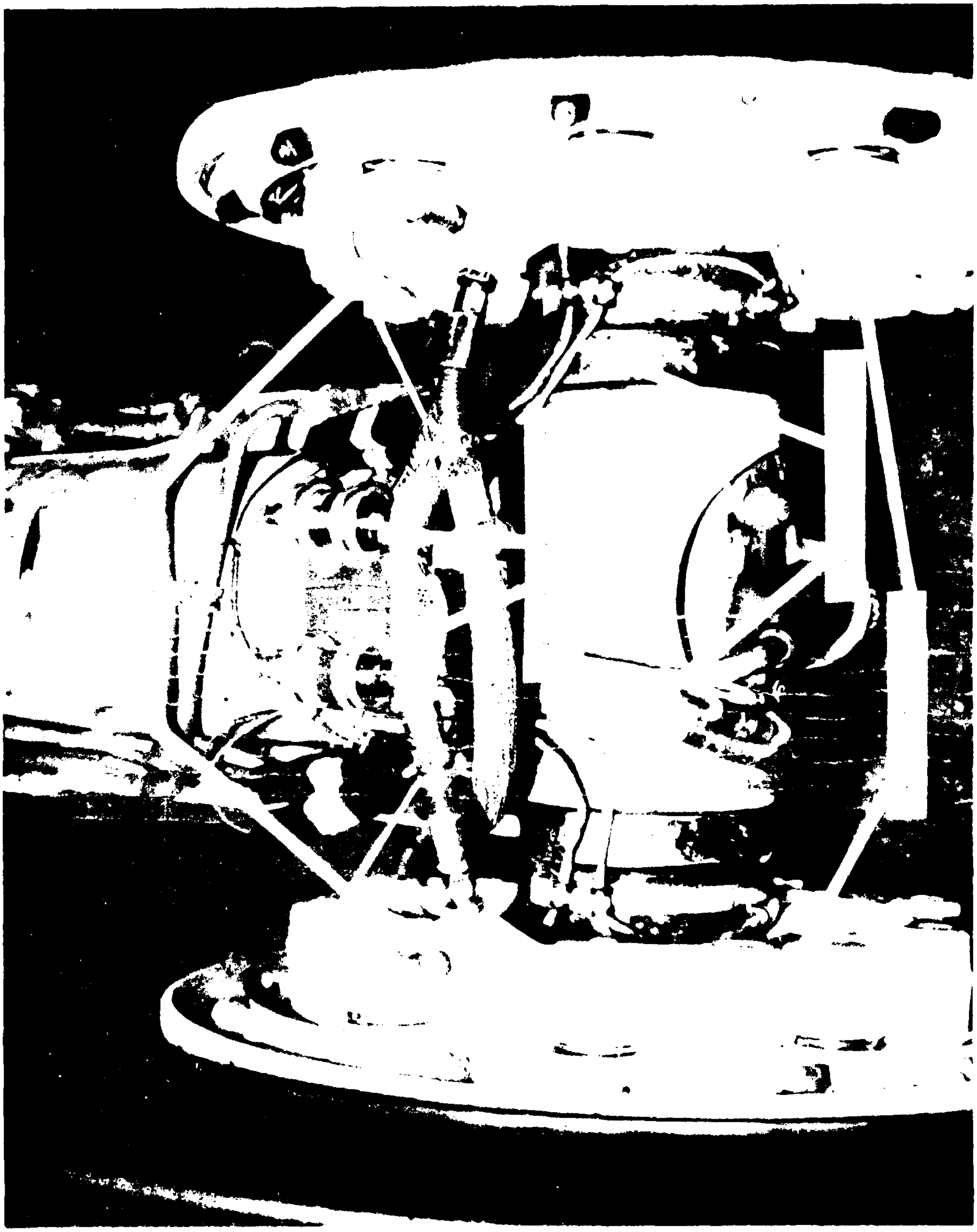


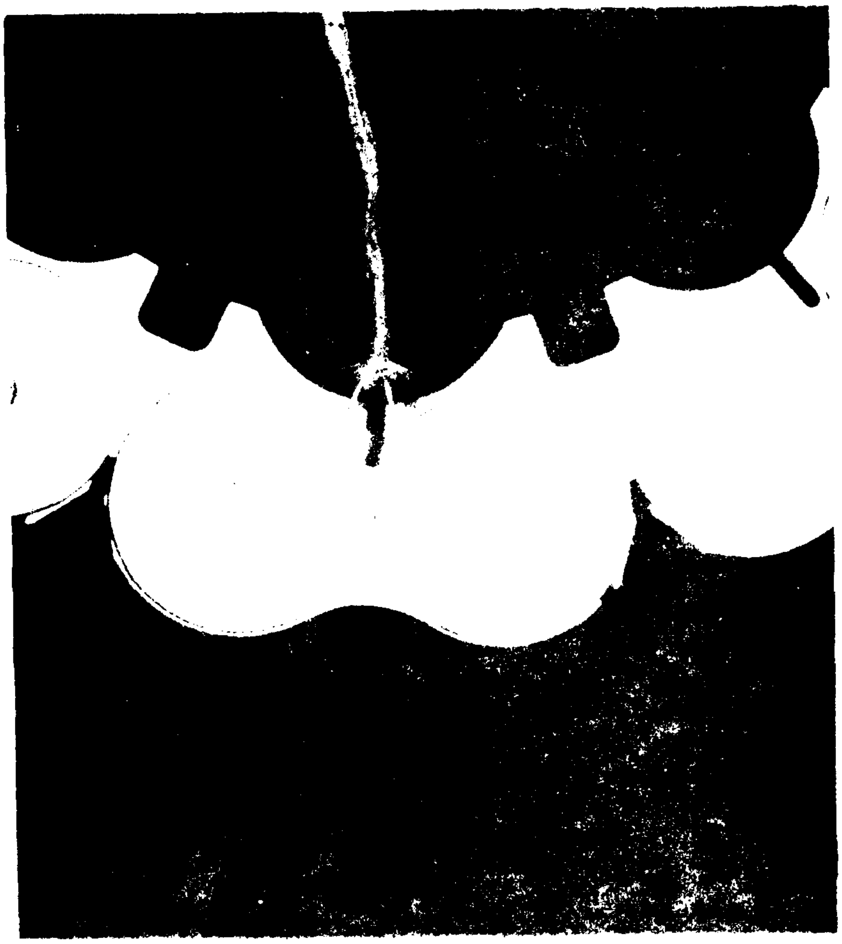
FIGURE 2 - FIREPROOF HYDRAULIC BRAKE SYSTEM DIAGRAM











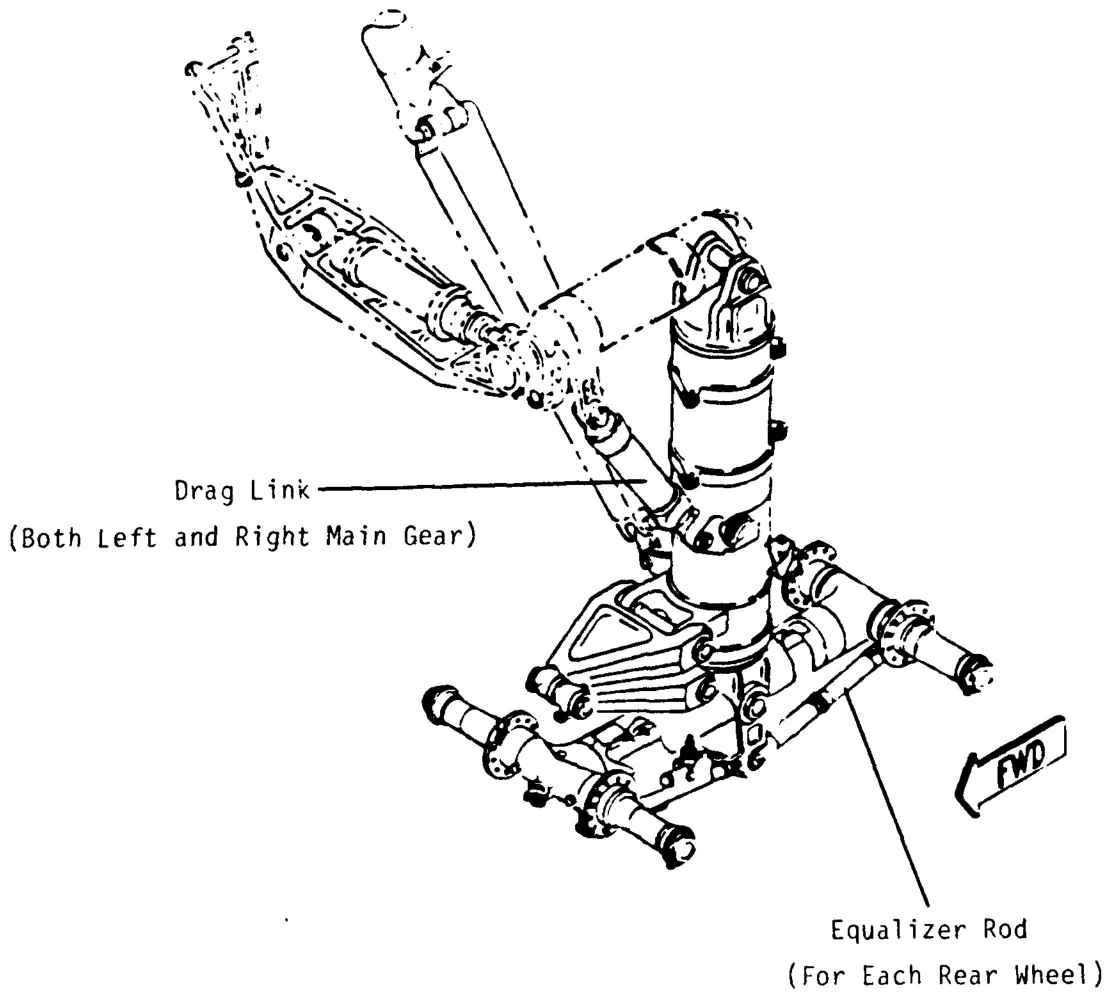
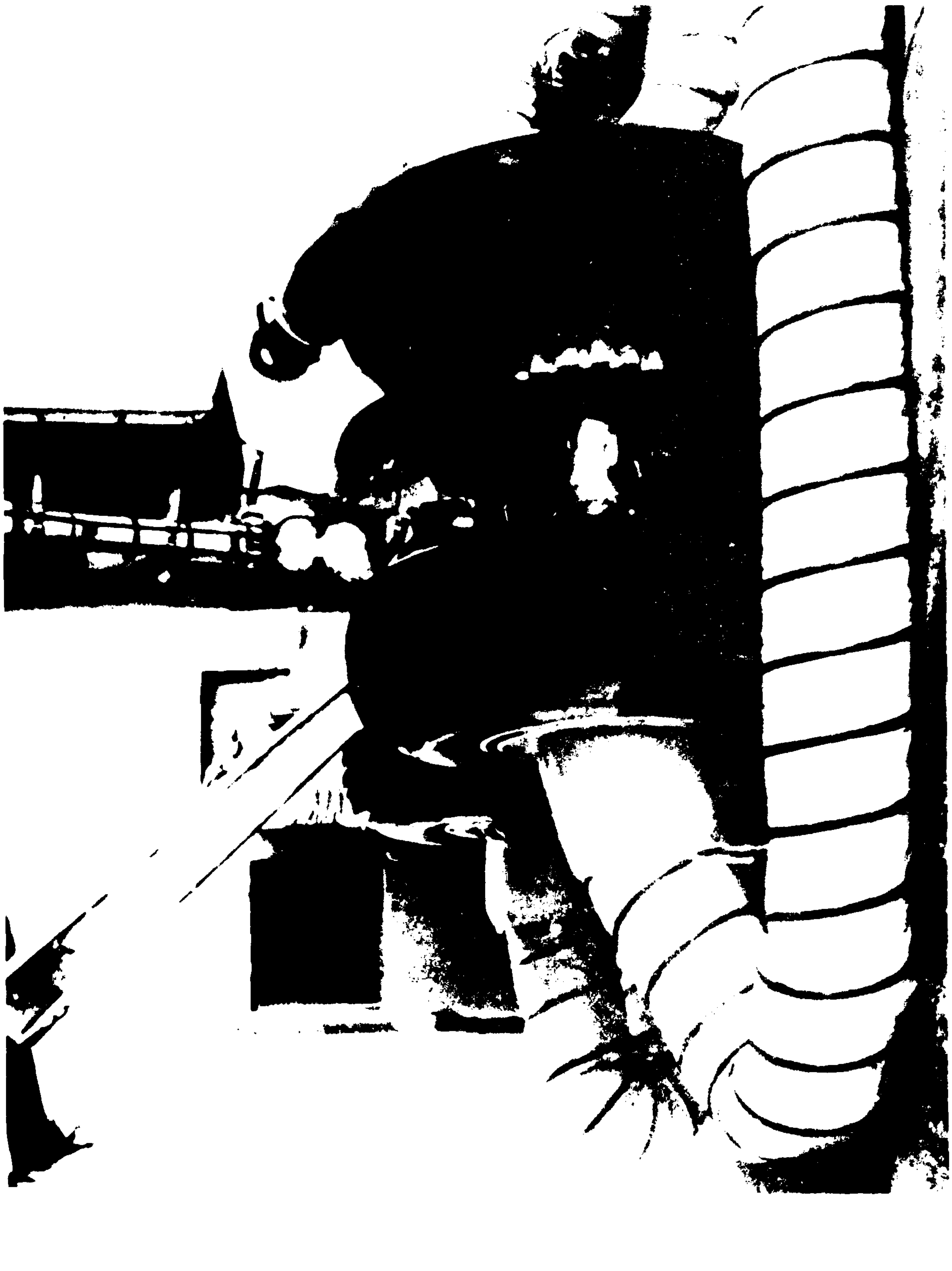


FIGURE 9 - STRAIN GAUGE LOCATIONS



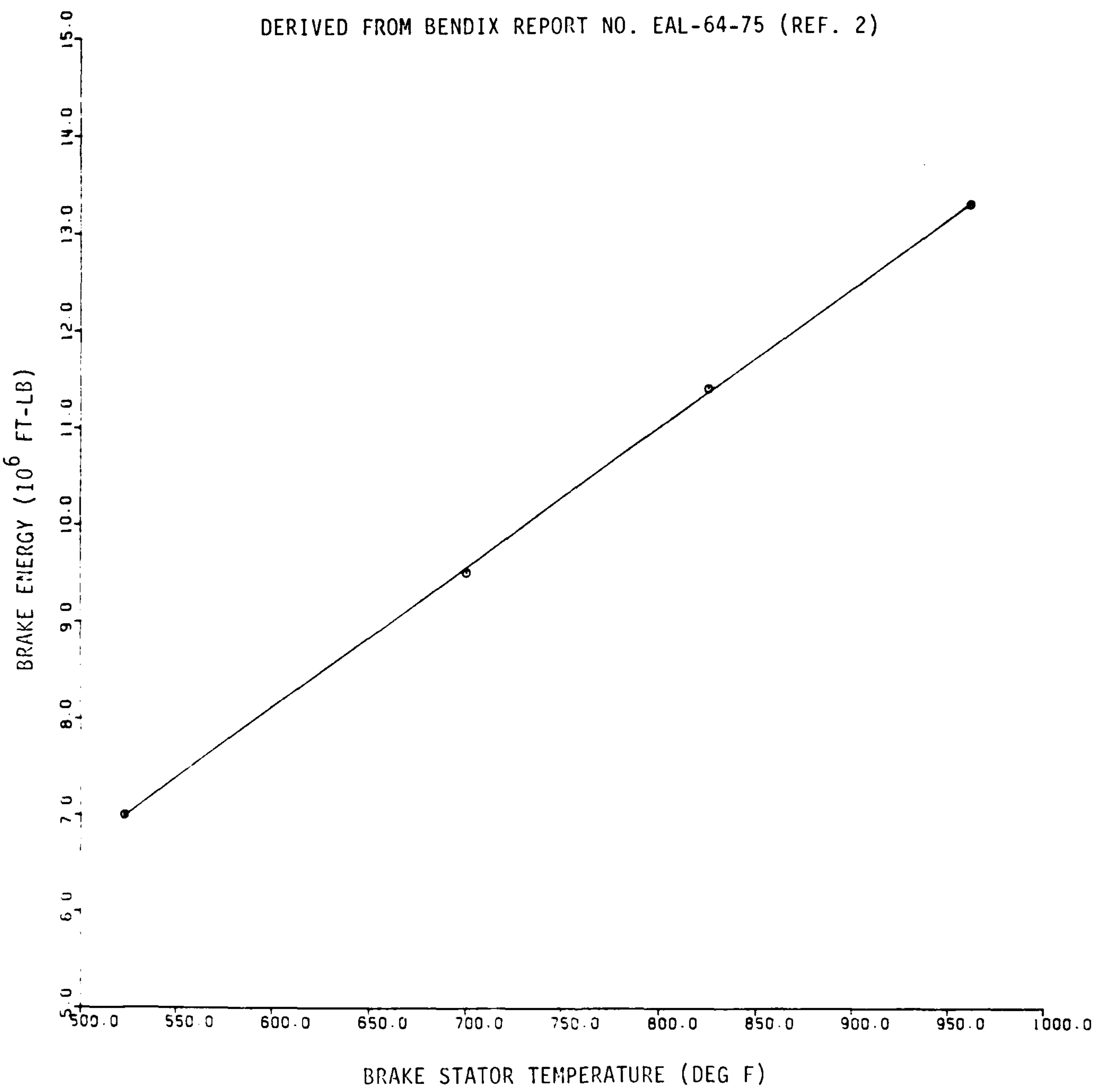


FIGURE 11 - BENDIX LABORATORY TEST DATA

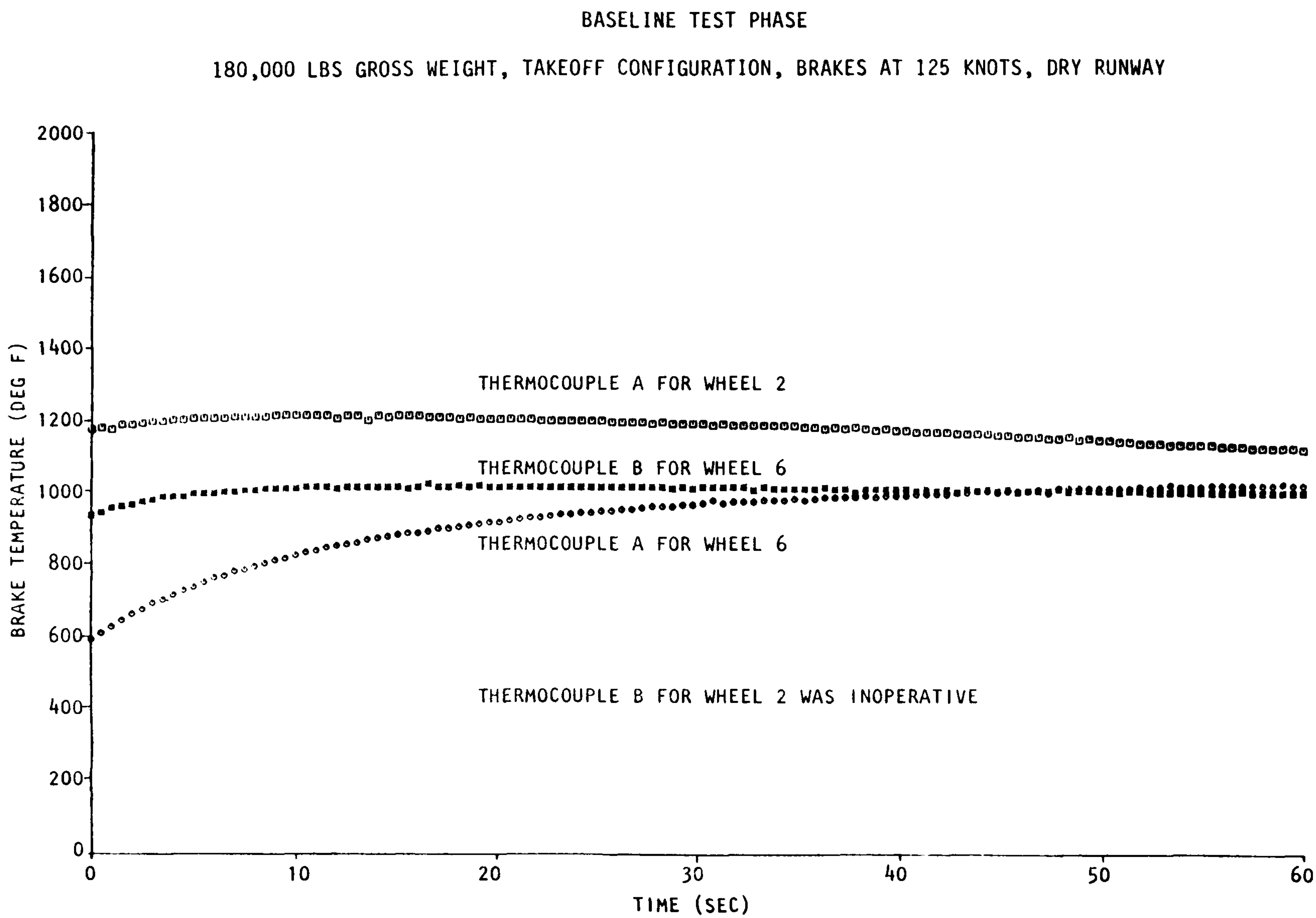


FIGURE 12 - BRAKE TEMPERATURE TIME HISTORY (SAMPLE)

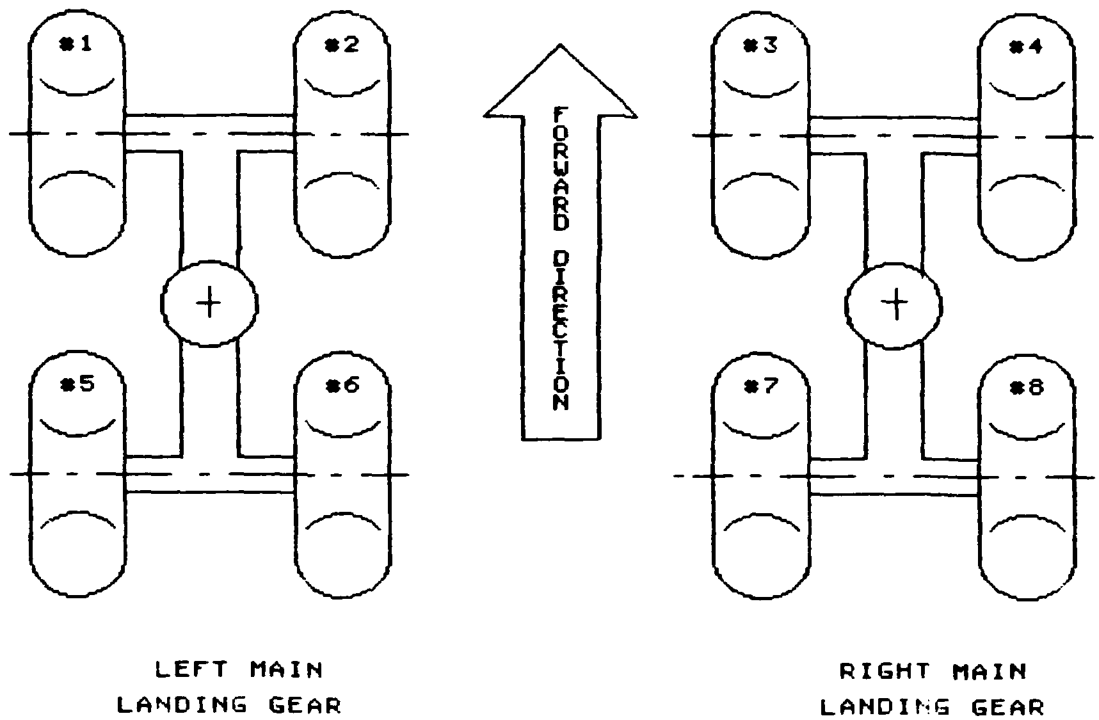


FIGURE 13 - WHEEL LAYOUT AND NUMERATION

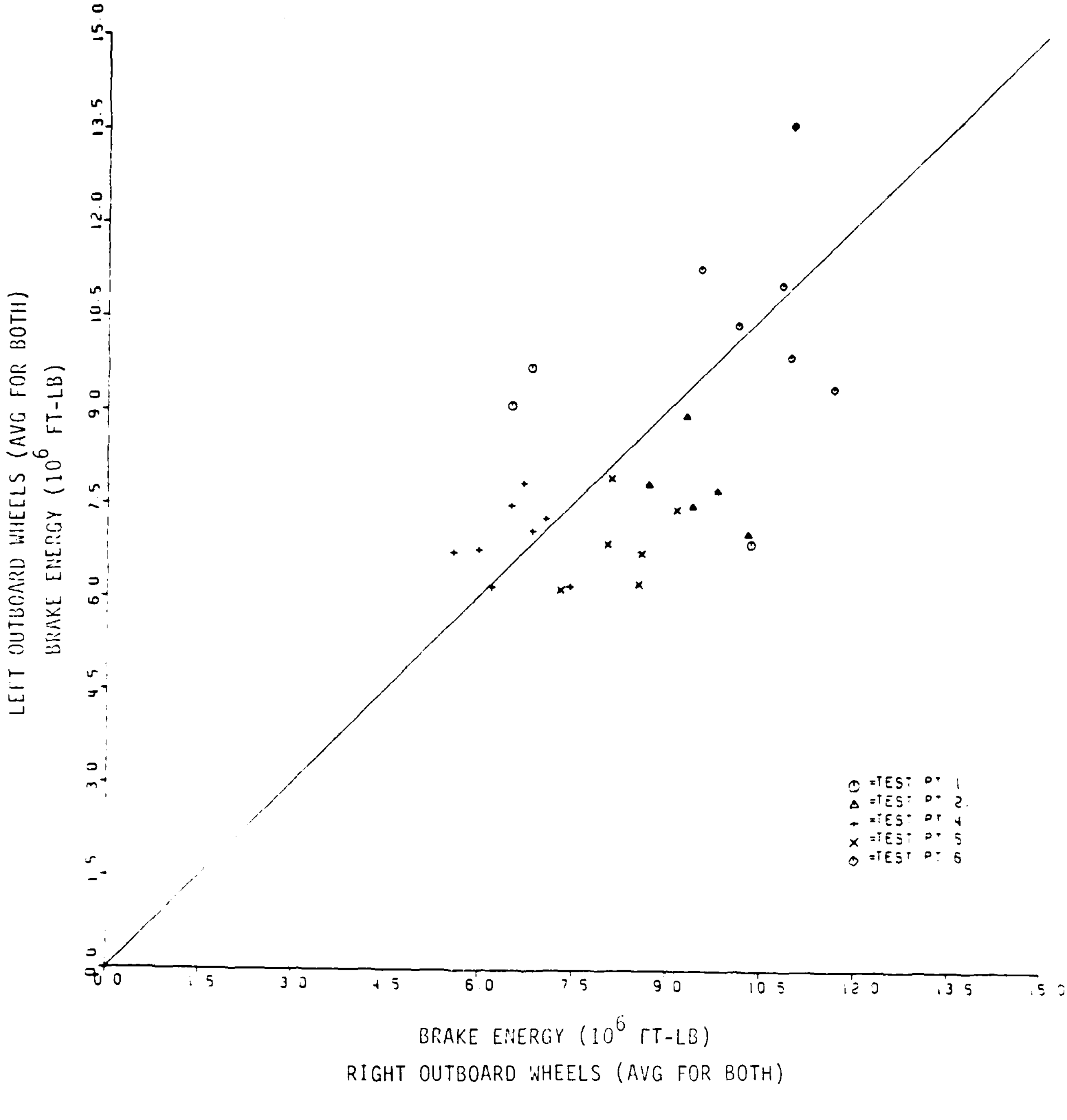


FIGURE 14 - BRAKE ENERGY SCATTER (THERMAL)
BASELINE TEST PHASE

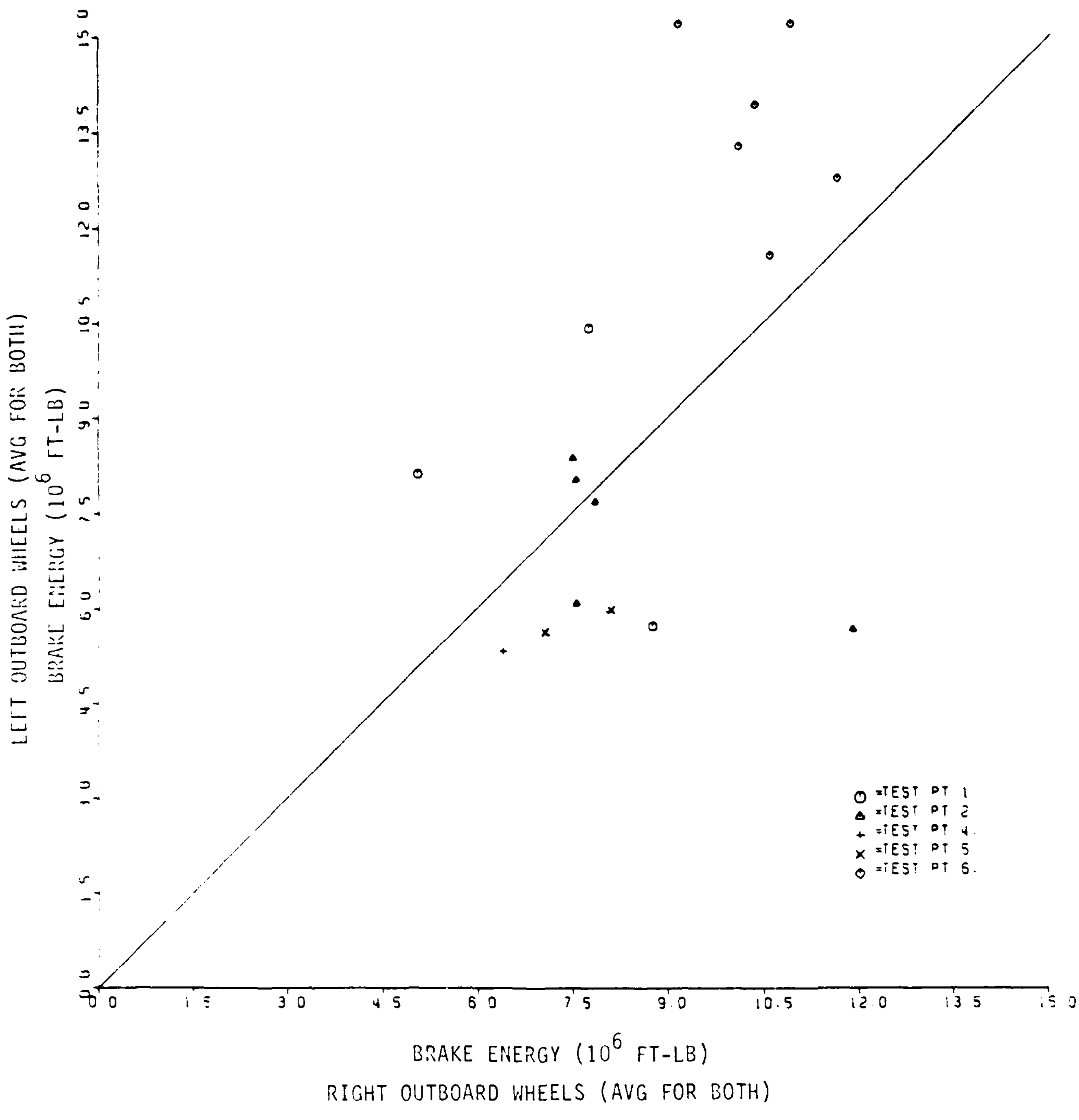


FIGURE 15 - BRAKE ENERGY SCATTER (STRAIN)
BASELINE TEST PHASE

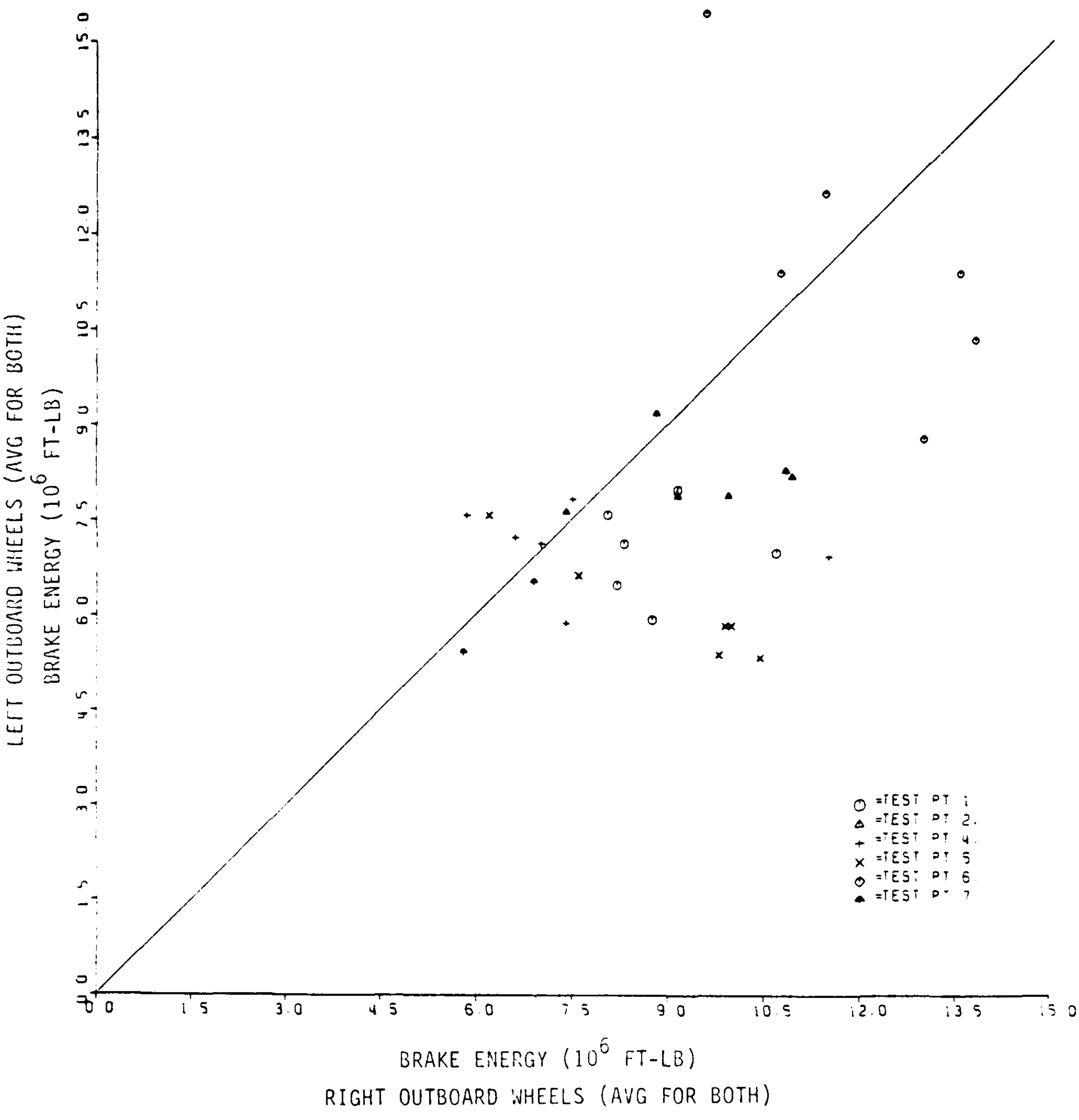


FIGURE 16 - BRAKE ENERGY SCATTER (THERMAL)
FHBS TEST PHASE

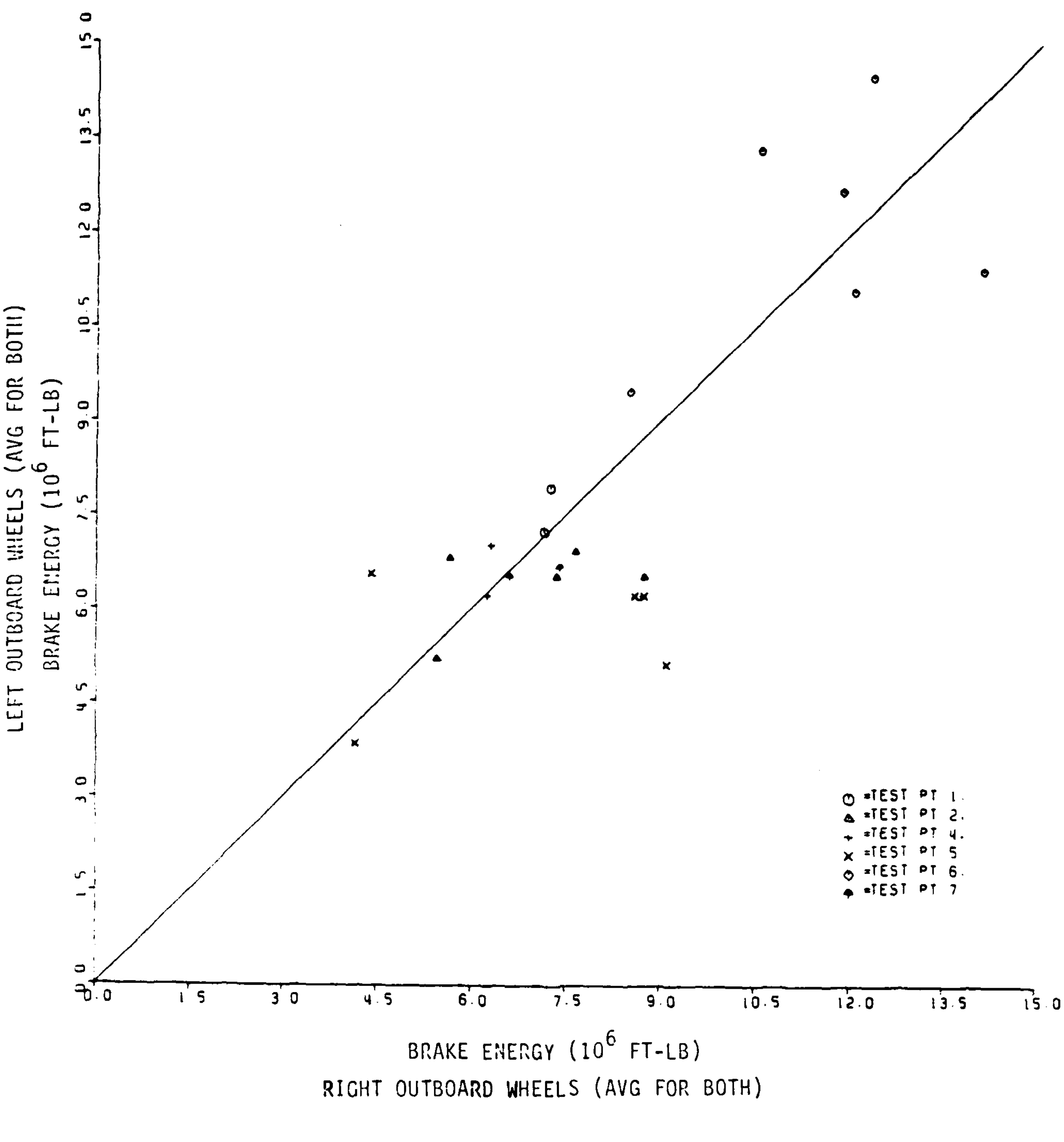


FIGURE 17 - BRAKE ENERGY SCATTER (STRAIN)
FHBS TEST PHASE

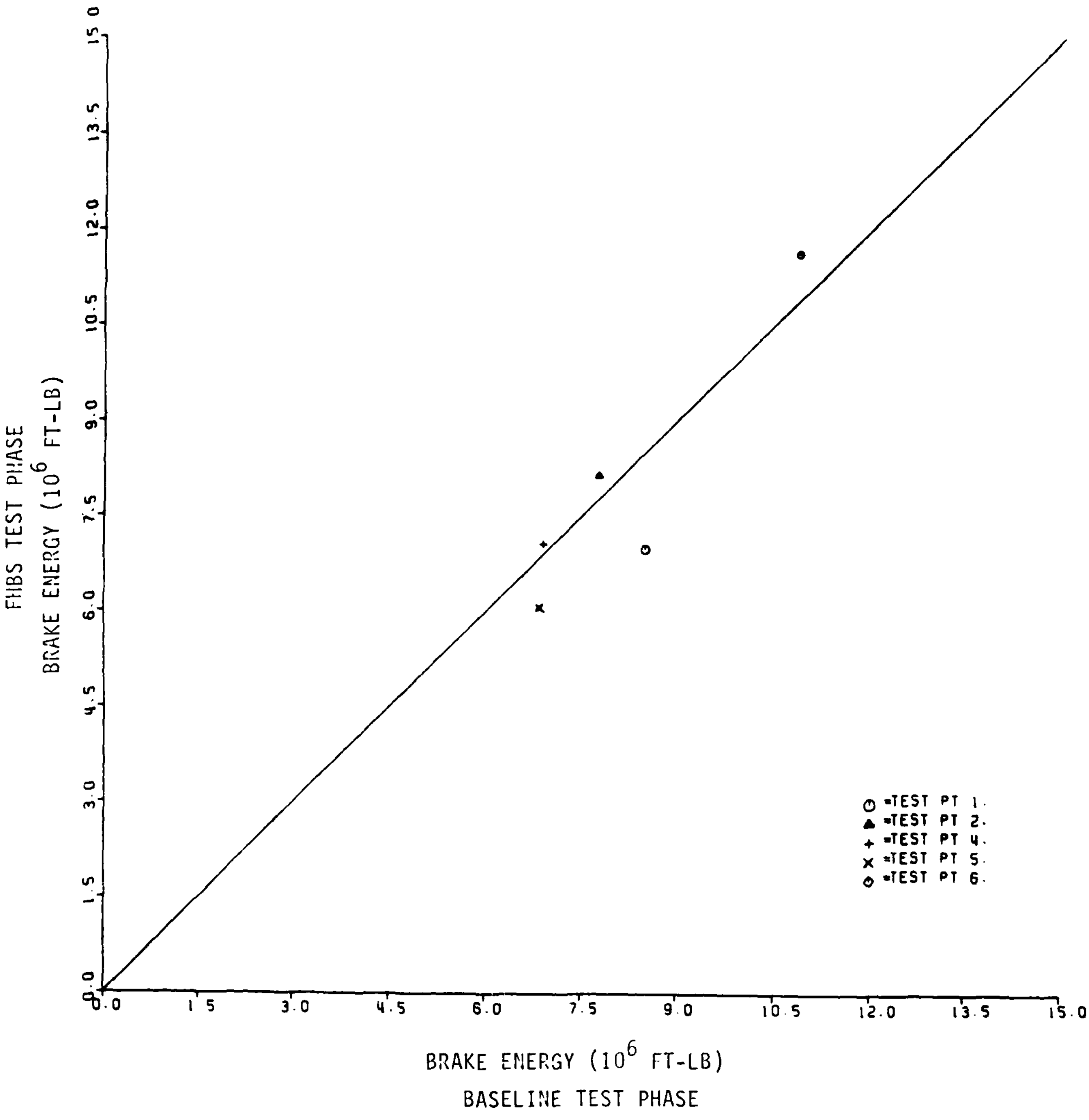


FIGURE 18 - AVERAGE LEFT OUTBOARD BRAKE ENERGY
(THERMAL)

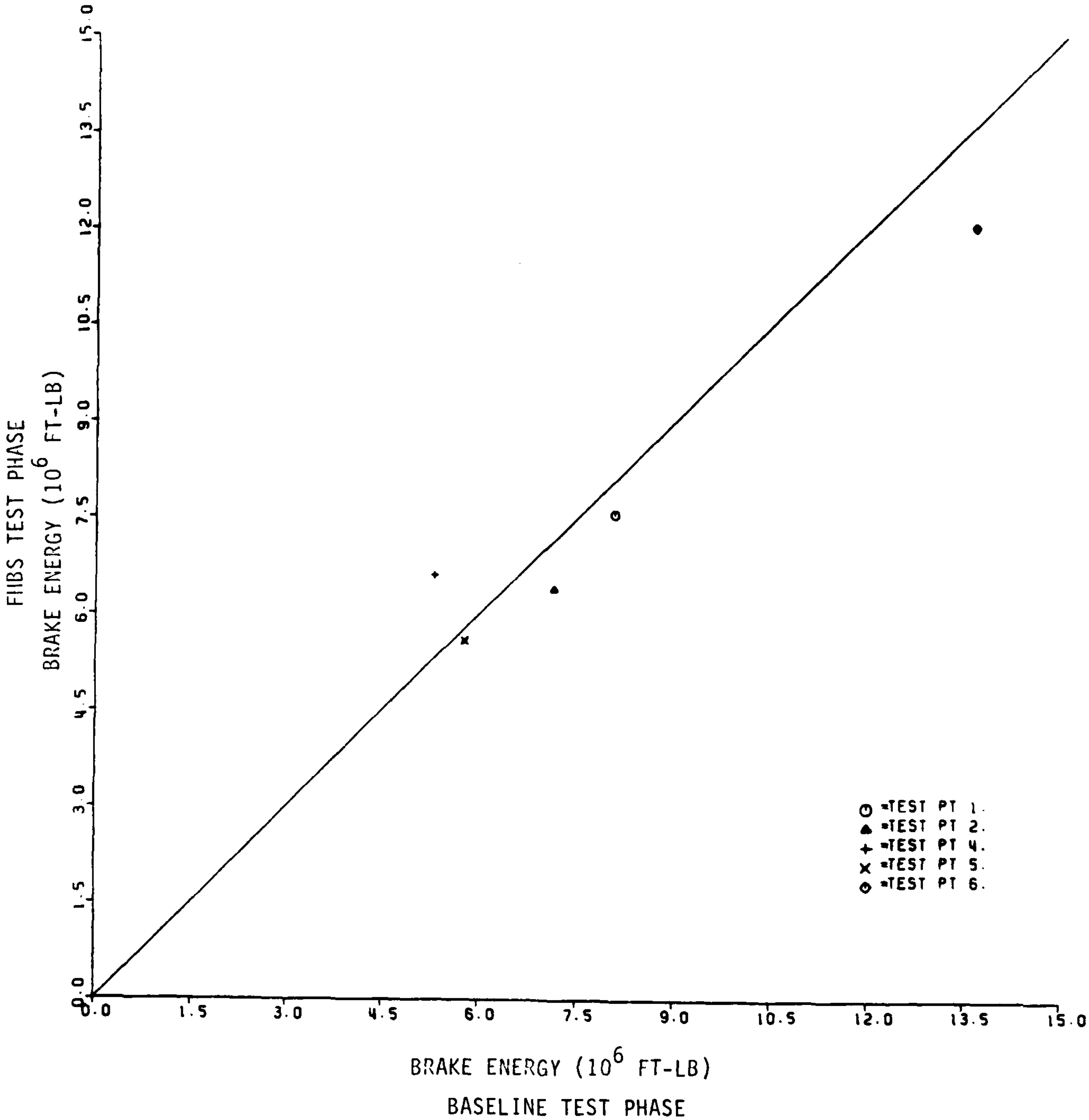
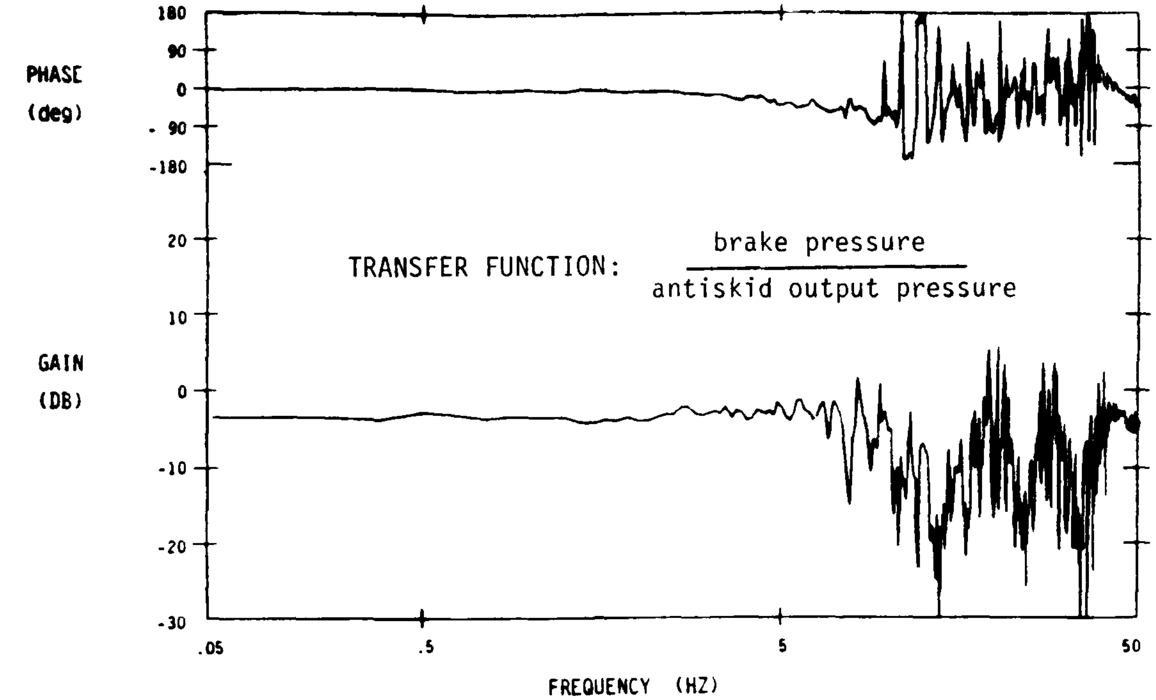


FIGURE 19 - AVERAGE LEFT OUTBOARD BRAKE ENERGY
(STRAIN)



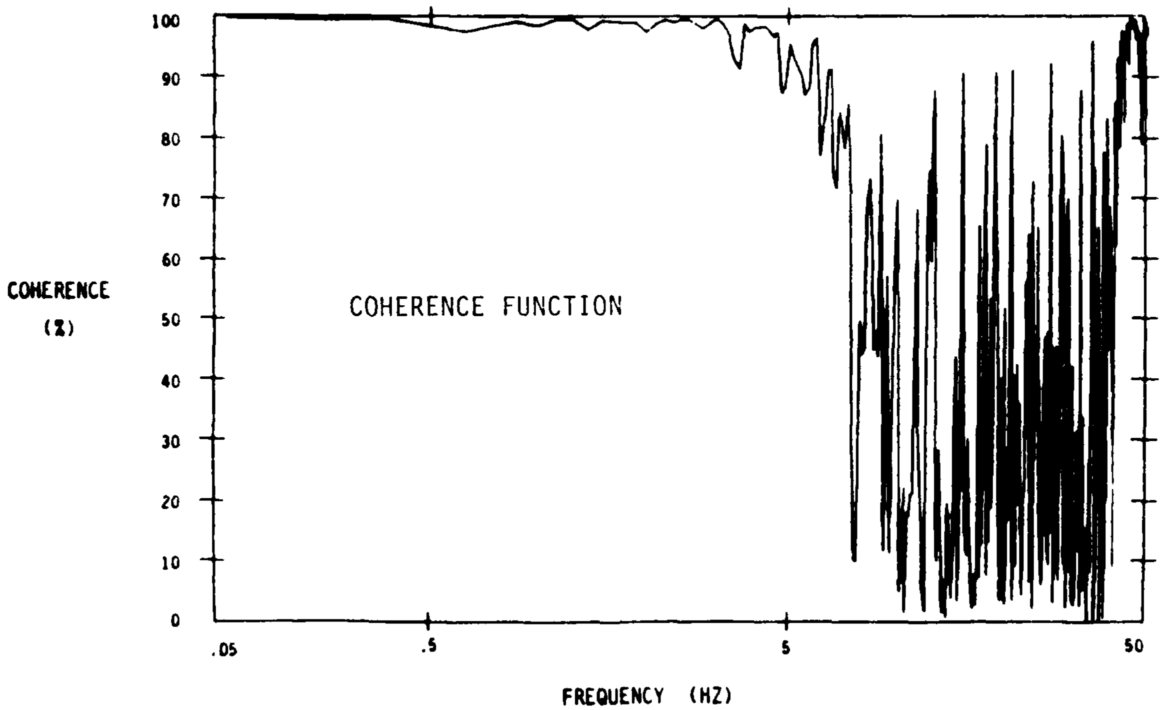
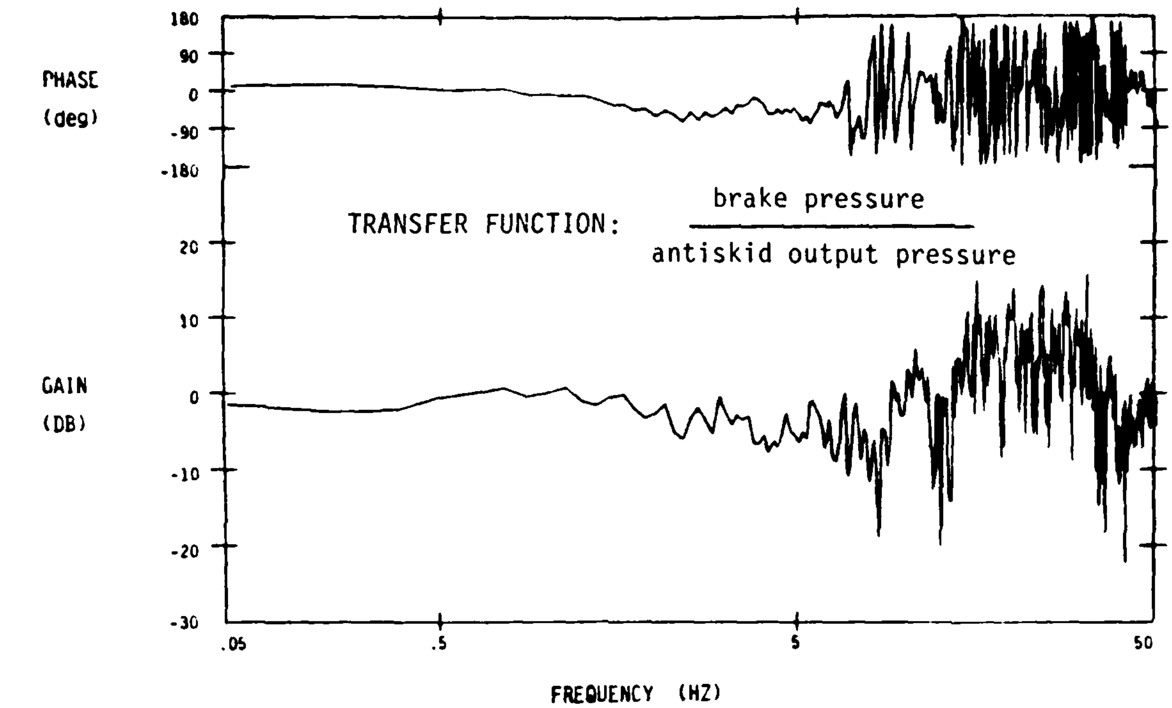


FIGURE 20 - BRAKE SYSTEM FREQUENCY ANALYSIS (BASELINE SAMPLE)



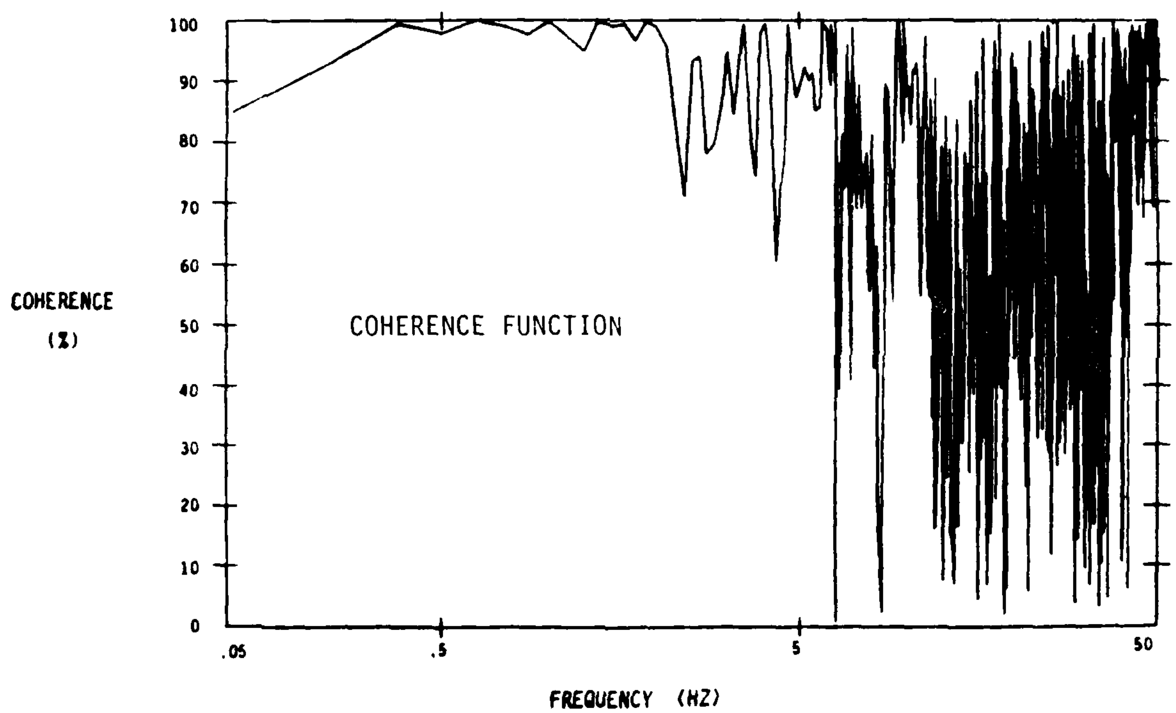


FIGURE 21 - BRAKE SYSTEM FREQUENCY ANALYSIS (FHBS SAMPLE)

FHBS TEST PHASE

150,000 LBS GROSS WEIGHT, TAKEOFF CONFIGURATION,

BRAKES AT 90 KNOTS, WET RUNWAY

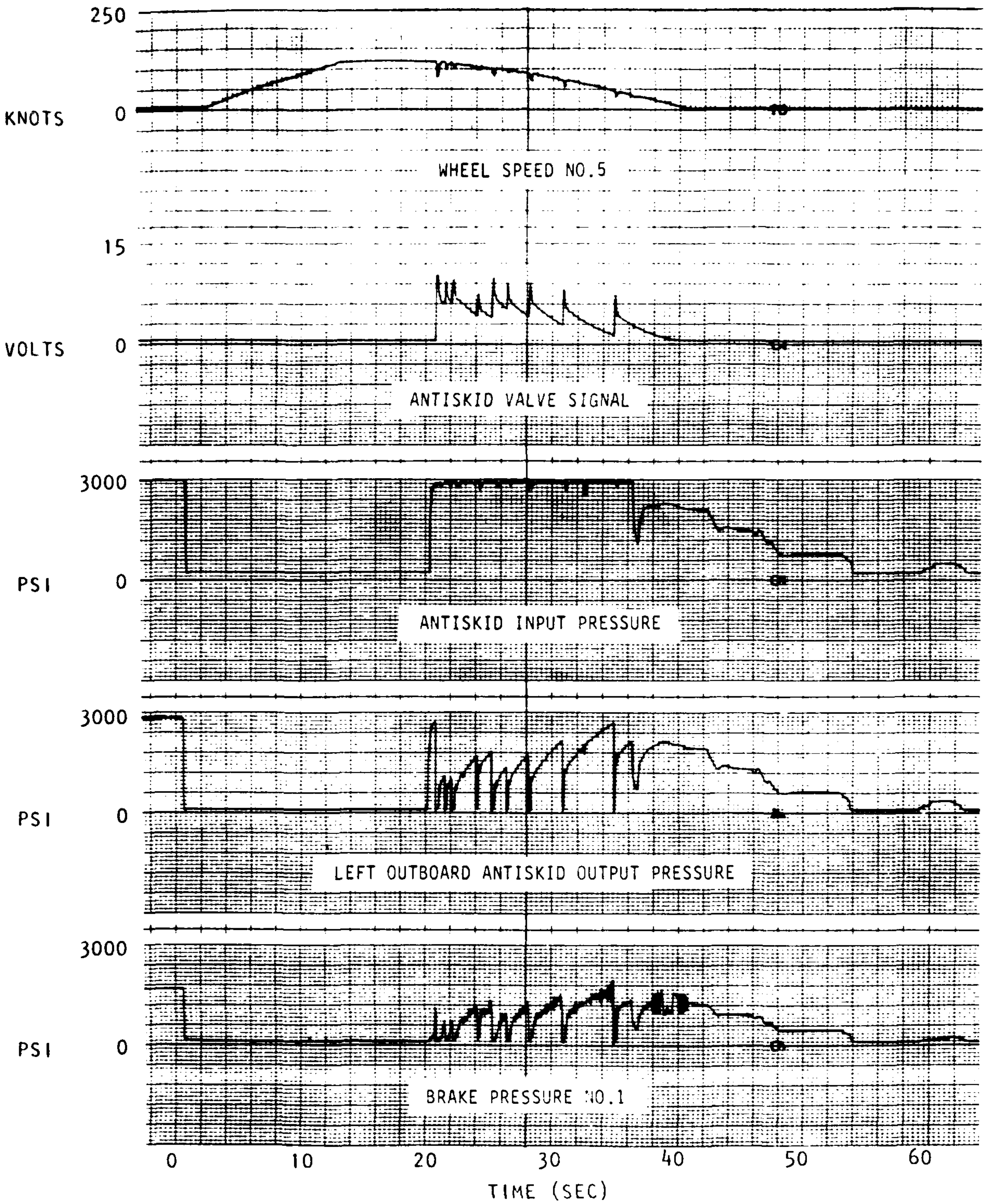


FIGURE 22 - STRIP CHART DATA (SAMPLE)

APPENDIX B

TABLES

TABLE 1

TEST POINTS

POINT NUMBER	AIRCRAFT GROSS WEIGHT	CONFIGURATION	BRAKE APPLICATION SPEED	RUNWAY CONDITION	RUNS DESIRED	RUNS COMPLETED (BASELINE)	RUNS COMPLETED (FHBS)
1	150,000 lbs	takeoff	100 knots	dry	6	2	6
2	165,000 lbs	takeoff	100 knots	dry	6	5	6
3	180,000 lbs	takeoff	125 knots	dry	6	point deleted	point deleted
4	150,000 lbs	landing	100 knots	dry	6	8	6
5	165,000 lbs	landing	100 knots	dry	6	6	6
6	180,000 lbs	landing	125 knots	dry	6	6	6
7	150,000 lbs	takeoff	90 knots	wet	2	0	2
8	150,000 lbs	landing	90 knots	wet	2	0	0
					total: 40	total: 27	total: 32

TABLE 2

BRAKE ENERGIES (in millions of ft-lbs)

BASELINE TEST PHASE, TEST POINT 1
150,000 lbs Gross Weight, Takeoff Configuration,
Brakes at 100 Knots, Dry Runway

PREDICTED	THERMAL					STRAIN				
7.8	9.0	10.9	10.3	6.3	Avg 9.0	8.0	8.2	8.7	4.2	Avg 7.6
	9.1	9.6	10.1	6.7		8.2	8.6	9.4	5.9	
9.0	8.2	10.9	8.8	6.5	Avg 9.0	10.2	9.0	9.4	6.4	Avg 9.3
	11.1	10.5	9.4	7.1		10.6	9.4	10.0	9.1	

NOTE: Eight additional runs were conducted, but were deleted. Seven of these were due to an antiskid problem which took some time to pinpoint. The other run was deleted due to excessive skidding of the outboard wheels due to differences in tire footprint between a new and an older tire.

Layout of brake energies is the same as the wheel layout (Fig. 13).

TABLE 3

BRAKE ENERGIES (in millions of ft-lbs)

BASELINE TEST PHASE, TEST POINT 2
165,000 lbs Gross Weight, Takeoff Configuration,
Brakes at 100 Knots, Dry Runway

PREDICTED	THERMAL					STRAIN				
9.8	7.5	11.5	10.2	8.4	Avg 9.6	7.7	9.8	9.4	6.8	Avg 9.0
	8.1	10.9	10.9	9.0		7.6	11.0	10.6	8.9	
9.8	7.0	11.5	11.7	9.3	Avg 9.9	7.8	10.3	9.4	6.3	Avg 9.0
	7.9	11.7	10.9	9.5		8.2	10.8	10.3	8.8	
9.5	7.6	10.5	11.0	9.6	Avg 9.8	5.9	8.6	8.1	6.4	Avg 7.7
	7.8	10.8	11.1	10.0		6.2	9.1	8.8	8.7	
9.5	9.1	9.9	11.5	9.0	Avg 10.1	8.4	10.5	9.5	6.4	Avg 9.2
	8.7	12.2	10.8	9.6		8.3	11.6	10.3	8.6	
9.4	6.5	12.4	11.5	10.0	Avg 10.1	5.6	8.8	8.2	6.6	Avg 7.7
	7.5	11.0	11.0	10.6		5.7	9.1	8.9	8.8	

NOTE: One additional run conducted was deleted due to the antiskid problem encountered in Test Point 1.

Layout of brake energies is the same as the wheel layout (Fig. 13).

TABLE 4

BRAKE ENERGIES

BASELINE TEST PHASE, TEST POINT 3
180,000 lbs Gross Weight, Takeoff Configuration,
Brakes at 125 Knots, Dry Runway

NOTE: Three runs were conducted; however, the entire test point was deleted since little or no antiskid cycling was observed at this condition.

TABLE 5

BRAKE ENERGIES (in millions of ft-lbs)

BASELINE TEST PHASE, TEST POINT 4
150,000 lbs Gross Weight, Landing Configuration,
Brakes at 100 Knots, Dry Runway

PREDICTED	THERMAL						STRAIN				
8.2	7.7	10.3	10.7	6.5	Avg 8.7	(1)	---	---	9.2	4.9	
	7.9	10.0	9.7	6.9			---	10.9	10.0	6.8	
8.2	6.6	10.9	10.3	6.5	Avg 8.7		---	---	9.3	4.4	
	8.3	9.9	10.4	6.5			---	9.8	9.9	5.9	
8.2	6.3	10.1	9.6	6.1	Avg 8.1		---	---	9.3	4.3	
	7.2	9.5	10.3	5.9			---	9.8	9.9	5.9	
8.2	6.3	10.2	10.5	5.4	Avg 8.0	(2)					
	7.1	9.3	9.8	5.8							
8.2	6.0	12.3	9.3	6.2	Avg 8.2		---	---	8.4	4.2	
	6.3	9.8	9.1	6.2			---	9.4	8.8	5.8	
9.0	5.4	11.6	10.6	6.6	Avg 8.6		5.6	10.4	9.4	5.4	Avg 8.0
	6.9	10.0	9.5	8.3			5.0	10.6	10.2	7.4	
8.7	7.6	8.5	9.4	6.6	Avg 8.3						
	6.5	10.7	10.1	7.1							
8.6	7.1	10.9	9.4	6.9	Avg 8.5						
	7.4	10.5	9.0	7.2							

NOTES: (1) Gaps in the strain gauge measured values are due to bad No. 1 equalizer rod signals. Because of the difference in values between outboard and inboard brake energies of this test condition, no average energy is shown.

(2) Laser tracking data was insufficient for computing the brake energies for three runs.

Layout of brake energies is the same as the wheel layout (Fig. 13).

TABLE 6

BRAKE ENERGIES (in millions of ft-lbs)

BASELINE TEST PHASE, TEST POINT 5
165,000 lbs Gross Weight, Landing Configuration,
Brakes at 100 Knots, Dry Runway

PREDICTED	THERMAL					STRAIN				
9.0	5.3	8.5	10.0	8.3	Avg 8.5	(1)				
	7.1	9.4	10.4	8.8						
8.7	5.4	10.7	10.9	6.7	Avg 8.4	5.6	9.9	9.0	6.1	Avg 7.9
	6.8	9.2	9.9	7.9		5.6	9.5	9.8	8.0	
9.4	7.7	11.0	10.4	7.0	Avg 9.2	(2)				
	8.1	10.3	10.1	9.2						
9.3	7.0	10.4	10.7	7.9	Avg 9.3					
	7.8	10.6	9.8	10.4						
9.2	6.0	11.8	10.4	7.7	Avg 9.1					
	7.7	10.4	10.0	8.4						
9.0	6.0	10.6	10.9	8.4	Avg 9.2	6.1	10.5	8.9	7.0	Avg 8.3
	7.4	10.2	11.1	8.8		5.8	9.9	9.3	9.2	

NOTES: (1) Laser tracking data was insufficient for computing the brake energies.

(2) The equalizer rod data was bad for three runs.

Layout of brake energies is the same as the wheel layout (Fig. 13).

TABLE 7

BRAKE ENERGIES (in millions of ft-lbs)

BASELINE TEST PHASE, TEST POINT 6
180,000 lbs Gross Weight, Landing Configuration,
Brakes at 125 Knots, Dry Runway

PREDICTED	THERMAL					STRAIN				
14.4	12.1	15.0	14.7	10.8	Avg 12.9	11.4	14.7	14.1	9.0	Avg 13.0
	9.9	15.1	14.9	10.8		11.7	15.5	15.1	12.2	
14.3	10.8	12.3	13.9	9.3	Avg 11.4	12.9	13.5	12.9	8.7	Avg 12.6
	9.9	11.9	12.0	10.9		13.6	14.3	13.4	11.5	
14.3	12.3	14.1	13.5	9.2	Avg 11.9	14.9	13.4	13.1	7.7	Avg 12.8
	10.2	13.2	12.6	9.8		15.4	13.9	13.5	10.6	
14.4	12.4	12.3	14.8	11.3	Avg 12.8	14.9	13.9	13.6	9.4	Avg 13.5
	14.7	13.6	12.9	10.6		15.4	14.6	13.7	12.4	
14.4	10.3	13.5	12.7	9.6	Avg 11.3	14.0	13.0	11.5	9.1	Avg 12.2
	9.4	11.7	11.6	12.3		13.8	13.2	11.6	11.6	
14.4	9.3	13.7	14.2	11.7	Avg 12.1	12.5	13.6	12.8	10.3	Avg 12.7
	9.4	14.9	12.1	11.6		13.0	14.3	12.9	13.0	

Layout of brake energies is the same as the wheel layout (Fig. 13).

TABLE 8

BRAKE ENERGIES

BASELINE TEST PHASE, TEST POINT 7
150,000 lbs Gross Weight, Takeoff Configuration,
Brakes at 90 Knots, Wet Runway

No testing was accomplished due to the lack of rain during the available testing period.

TABLE 9

BRAKE ENERGIES

BASELINE TEST PHASE, TEST POINT 8
150,000 lbs Gross Weight, Landing Configuration,
Brakes at 90 Knots, Wet Runway

One run was conducted but was deleted due to the antiskid problem encountered earlier during the baseline test phase. No additional runs were made due to the lack of rain during the available testing period.

TABLE 10

BRAKE ENERGIES (in millions of ft-lbs)

FHBS TEST PHASE, TEST POINT 1
150,000 lbs Gross Weight, Takeoff Configuration,
Brakes at 100 Knots, Dry Runway

PREDICTED	THERMAL					STRAIN				
8.7	8.0	11.5	9.6	8.8	Avg 9.9	7.3	10.8	9.7	6.0	Avg 9.3
	7.9	12.8	11.5	9.5		8.5	12.6	10.7	8.5	
8.7	6.8	10.8	10.9	9.1	Avg 9.1	7.1	9.6	8.9	6.4	Avg 8.4
	7.4	10.0	10.4	7.5		7.3	10.3	9.9	7.9	
8.7	7.1	13.2	11.6	8.8	Avg 9.9	[1] ---	---	8.9	5.4	
	5.8	12.5	12.3	7.6		---	10.6	9.8	7.8	
8.7	5.9	12.1	10.1	8.6	Avg 8.9	---	---	8.5	6.9	
	5.9	10.9	9.2	8.9		---	10.6	9.5	8.7	
8.6	6.5	11.5	10.9	10.3	Avg 9.8	---	---	8.7	7.4	
	7.4	9.8	10.6	11.1		---	10.1	9.7	9.4	
8.7	7.4	11.0	11.6	8.2	Avg 9.6	[2]				
	7.7	11.4	11.2	7.9						

NOTES: [1]Equalizer rod No. 1 data was bad for three runs.

[2]Laser tracking data was insufficient for computing the brake energies.

Layout of brake energies is the same as the wheel layout (Fig. 13).

TABLE 11

BRAKE ENERGIES (in millions of ft-lbs)

FHBS TEST PHASE, TEST POINT 2
165,000 lbs Gross Weight, Takeoff Configuration,
Brakes at 100 Knots, Dry Runway

PREDICTED	THERMAL					STRAIN				
9.7	8.3	10.9	11.8	10.3	Avg 10.6	6.5	8.5	8.0	7.6	Avg 8.2
	8.2	11.3	12.2	11.4		6.5	8.8	9.7	9.9	
9.7	7.3	10.8	11.0	10.3	Avg 9.7	6.2	8.6	7.4	7.0	Avg 7.7
	8.4	10.7	9.6	9.6		6.8	8.6	8.6	8.7	
9.3	7.7	10.5	11.6	10.8	Avg 10.3	6.7	8.4	8.3	6.6	Avg 8.0
	8.6	10.7	11.8	11.1		7.1	8.5	9.4	8.7	
9.1	7.3	9.8	10.1	7.7	Avg 8.7	6.6	7.9	7.4	4.9	Avg 7.0
	7.9	9.6	10.1	7.1		7.0	7.7	8.3	6.4	
9.3	7.5	11.1	11.7	9.1	Avg 9.8	5.2	6.5	5.7	4.8	Avg 5.8
	8.2	10.6	11.4	9.2		5.2	6.6	6.7	6.1	
9.3	9.0	10.5	11.9	8.2	Avg 10.0	*				
	9.3	10.0	11.7	9.4						

*NOTE: Laser tracking data was insufficient for computing the brake energies.

Layout of brake energies is the same as the wheel layout (Fig. 13).

TABLE 12

BRAKE ENERGIES

FHBS TEST PHASE, TEST POINT 3
180,000 lbs Gross Weight, Takeoff Configuration,
Brakes at 125 Knots, Dry Runway

No runs were attempted for this test condition since little or no antiskid cycling was noted for the baseline runs. This test point has been deleted.

TABLE 13

BRAKE ENERGIES (in millions of ft-lbs)

FHBS TEST PHASE, TEST POINT 4
150,000 lbs Gross Weight, Landing Configuration,
Brakes at 100 Knots, Dry Runway

PREDICTED	THERMAL					STRAIN				
8.5	6.9	9.6	10.1	7.1	Avg 8.3	*---	---	9.2	5.9	
	6.9	9.9	8.9	6.8		---	9.2	9.5	7.1	
8.4	7.2	9.6	10.6	5.8	Avg 8.3	---	---	9.9	4.5	
	7.9	9.6	9.7	5.9		---	9.2	9.6	5.8	
8.4	7.0	11.1	11.1	6.0	Avg 8.8	---	---	9.0	4.8	
	7.4	10.3	10.4	7.2		---	9.2	9.1	6.0	
8.5	5.6	9.4	9.8	7.4	Avg 8.0	---	---	9.3	5.5	
	6.1	8.8	9.7	7.4		---	8.7	9.4	7.3	
8.5	7.8	9.9	10.5	7.1	Avg 8.8	6.9	10.1	8.7	5.5	Avg 8.1
	7.9	9.7	9.6	7.9		7.1	9.8	9.3	7.1	
8.5	7.2	10.8	11.3	6.8	Avg 8.8	6.2	10.0	8.9	5.4	Avg 7.8
	7.0	10.3	10.0	7.2		6.2	9.8	9.1	7.1	

*NOTE: Equalizer rod No. 1 data was bad for four runs.

Layout of brake energies is the same as the wheel layout (Fig. 13).

TABLE 14

BRAKE ENERGIES (in millions of ft-lbs)

FHBS TEST PHASE, TEST POINT 5
165,000 lbs Gross Weight, Landing Configuration,
Brakes at 100 Knots, Dry Runway

PREDICTED	THERMAL					STRAIN				
9.3	5.6	11.4	11.3	9.5	Avg 9.5	6.0	11.5	10.4	7.0	Avg 9.0
	6.0	11.5	10.6	10.5		6.4	10.6	10.1	10.2	
9.2	5.6	10.0	11.3	9.7	Avg 9.2	6.3	11.0	9.6	7.9	Avg 8.9
	6.0	10.1	11.0	10.1		6.1	10.2	10.3	9.6	
9.2	4.9	9.6	10.4	9.7	Avg 8.8	*				
	5.8	10.0	10.2	9.9						
9.2	5.4	10.5	10.7	10.4	Avg 9.1	5.2	10.9	9.0	8.1	Avg 8.5
	5.2	10.6	10.0	10.5		5.0	10.1	9.9	10.1	
9.2	6.7	9.4	10.2	7.5	Avg 8.5					
	6.5	9.8	10.5	7.7						
9.0	7.7	10.7	10.6	6.1	Avg 8.7	6.5	9.0	8.7	3.7	Avg 7.2
	7.4	10.6	9.9	6.3		6.6	8.6	9.2	5.1	

*NOTE: Laser tracking data was insufficient for computing the brake energies for two runs.

Layout of brake energies is the same as the wheel layout (Fig. 13).

TABLE 15

BRAKE ENERGIES (in millions of ft-lbs)

FHBS TEST PHASE, TEST POINT 6
180,000 lbs Gross Weight, Landing Configuration,
Brakes at 125 Knots, Dry Runway

PREDICTED	THERMAL					STRAIN				
14.5	11.2	15.2	16.3	12.9	Avg 13.8	12.3	14.6	14.3	10.2	Avg 13.6
	11.5	13.6	15.1	14.2		13.0	15.2	15.4	13.5	
14.5	10.7	14.0	13.1	10.4	Avg 12.4	9.3	11.9	10.8	7.4	Avg 10.3
	12.0	13.5	14.1	11.1		9.6	11.7	11.9	9.6	
14.3	12.7	14.8	15.4	10.7	Avg 13.0	13.1	14.0	13.2	9.0	Avg 12.9
	12.5	13.4	12.4	12.2		13.5	14.3	13.9	12.1	
14.5	9.0	12.7	13.3	13.5	Avg 12.6	10.9	13.7	11.4	10.6	Avg 12.2
	11.6	13.9	12.6	14.1		11.2	13.8	12.2	13.5	
14.3	14.9	15.7	15.5	9.3	Avg 14.3	14.1	14.9	13.3	15.5	Avg 14.1
	15.9	16.9	16.6	9.8		14.8	16.2	15.0	9.1	
14.3	7.6	10.8	11.9	13.3	Avg 11.3	11.4	15.0	10.2	15.2	Avg 13.0
	9.9	13.5	11.0	12.7		11.4	15.3	12.3	13.0	

Layout of brake energies is the same as the wheel layout (Fig. 13).

TABLE 16

BRAKE ENERGIES (in millions of ft-lbs)

FHBS TEST PHASE, TEST POINT 7
150,000 lbs Gross Weight, Takeoff Configuration,
Brakes at 90 Knots, Wet Runway

PREDICTED	THERMAL					STRAIN			
(1)	5.0	9.7	8.9	5.7	Avg 7.5	6.8	9.1	(2)---	---
	5.8	9.8	8.9	5.9		6.2	9.8	7.6	6.6
	5.9	10.2	8.6	6.1	Avg 8.4	7.3	8.3	---	---
	7.1	10.1	10.2	7.7		6.0	10.1	8.5	7.4

NOTES: (1) The aircraft operating charts could not be used to predict wet runway conditions. These charts were designed to a Runway Condition Reading (RCR) of 23.

(2) The front wheel energies for the right gear could not be calculated due to bad drag strut strain gauge data.

Layout of brake energies is the same as the wheel layout (Fig. 13).

TABLE 17

BRAKE ENERGIES

FHBS TEST PHASE, TEST POINT 8
150,000 lbs Gross Weight, Landing Configuration,
Brakes at 90 Knots, Wet Runway

No testing was accomplished due to lack of rain during the available testing period.

TABLE 18

STATISTICAL ANALYSIS RESULTS

Observed Brake Energy Differences of Outboard Wheels
(FHBS - Standard System)

Units in Millions of Ft-lbs

TEST POINT		THERMAL DATA	STRAIN DATA
1	No. of Samples	240	72
	Avg Difference	-1.53	-.05
	Standard Deviation	1.54	1.76
2	No. of Samples	384	300
	Avg Difference	-.82	-.90
	Standard Deviation	1.39	1.46
4	No. of Samples	528	88
	Avg Difference	.30	.80
	Standard Deviation	1.69	1.95
5	No. of Samples	432	128
	Avg Difference	-1.98	-1.18
	Standard Deviation	1.69	1.95
6	No. of Samples	432	432
	Avg Difference	.44	.17
	Standard Deviation	2.69	2.82

WEIGHTED COMPOSITE AVERAGE DIFFERENCE (THERMAL) =

$$\frac{(-1.53)(240)+(-.82)(384)+(.3)(528)+(-1.98)(432)+(.44)(432)}{240+384+528+432+432} = -.59$$

WEIGHTED COMPOSITE AVERAGE DIFFERENCE (STRAIN) =

$$\frac{(-.05)(72)+(-.9)(300)+(.8)(88)+(-1.18)(128)+(.17)(432)}{72+300+88+128+432} = -.27$$

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